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BULLETIN OF THE DEPARTMENT OF
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GEOLOGY OF A PART OF THE SANTA YNEZ RIVER DISTRICT, SANTA BARBARA COUNTY, CALIFORNIA

BY
WILLIAM S. W. KEW

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INTRODUCTION

The first investigation of the Santa Ynez River district was undertaken to obtain, if possible, some palaeontologic or stratigraphic evidence as to the age of the Franciscan rocks which are exposed in this region. With this end in view, the writer, together with Mr. N. L. Taliaferro, spent two weeks during June, 1914, in the vicinity of Redrock Cañon, which is a tributary of the Santa Ynez River in the western part of the district. Unfortunately, the Franciscan series in this region, as in other places, proved to be barren of any evidence which would indicate its age. Nevertheless, the country afforded some interesting problems, the study of which has given some information that is a contribution to the stratigraphy of California. An important structural question presented was the cause for the difference in direction between the Santa Ynez Mountains and the San Rafael Mountains. To investigate this two more trips were made, one in the summer of 1915 with Dr. E. F. Davis and the other in 1916 with Mr. K. H. Schilling. To both of these gentlemen, the writer is under obligations for the use of their notes.

Acknowledgment is made to Professor A. C. Lawson, under whose supervision this work was carried on, for valuable criticism and advice. The writer also takes this opportunity to thank the U. S. forest rangers of the Santa Barbara National Forest for their uniform courtesy.

LOCATION AND TOPOGRAPHY

The area to be described lies in the southern part of Santa Barbara County, California, and extends fifteen miles north from the Santa Barbara Channel with a breadth of about eighteen miles, forming a rectangular area of approximately 270 square miles. The northern part, where most of the work was done, is in the southern portion of the Santa Ynez quadrangle, and the remainder is covered by the Santa Barbara and Goleta Special maps. The term "Santa Ynez River district" as used in this paper includes the southern half of Santa Barbara County. It also embraces a portion of the Santa Ynez Mountains and the southern slope of the San Rafael Mountains, the latter being a local division of the California Coast Ranges.

Fig. 1. Index map of a part of California, showing location of area discussed in this report and areas on which reports have been published.

The San Rafael Mountains have the same northwesterly trend as the Coast Ranges in general. They are extremely rugged and quite irregular, since they are made up of a series of ridges usually determined by the strike of the strata of which they are composed. The main crest rises to an elevation of 6828 feet in Big Pine Mountain and 6581 feet in Mission Pine (San Rafael) Mountain. Within the area studied, Little Pine Mountain (4174 feet) is the highest elevation and is the culminating point of a long ridge which extends northwesterly from Indian Creek to Santa Cruz Creek. Loma Alta Mountain (2745 feet), although comparatively low, forms a prominent landmark in the western border of the area.

The Santa Ynez Mountains rise abruptly from the low, broad ocean terraces on the south to a comparatively even crest line with an average height of about 3500 feet. The greatest elevation is Santa Ynez Peak, 4292 feet high. The range is very narrow and extends from Point Arguello, just north of Point Conception, for forty miles in an easterly direction to a junction with the Coast Ranges proper. In its entirety, the range is very simple, being made up of a remarkably straight, single ridge, which has practically no large spurs or cañons.

The drainage of this district is concentrated in the Santa Ynez River which lies in the triangular-shaped lowlands between the two ranges. Its course runs nearly west for its entire length at the northern base of the Santa Ynez Mountains. The upper part of the river is confined in a narrow cañon, but to the west it gradually widens out, until opposite Loma Alta Mountain the bed of the stream forms but a small part of a widely terraced flood plain. In no part within the area studied is the river now corrading its trench; on the contrary it appears to be engaged in the work of aggradation. The tributaries entering the main stream reach back to the main divide, a distance of about ten miles or more. The most important of these are Mono Creek and Santa Cruz Creek. These streams cut across the strike of the formations, whereas Buckhorn and Gamusa creeks follow the trend of the strata. All the north side streams are low grade and in only a few places are they corrading vertically. In some of the larger cañons, as the Mono, there are terraces representing former flood plains of the stream.

In marked contrast to the drainage on the north side of the river, that of the Santa Ynez Mountains is short, high grade, and incisive. Some of the streams are so steep that it is impossible to ascend the cañons as they are blocked by huge boulders and stepped by waterfalls.

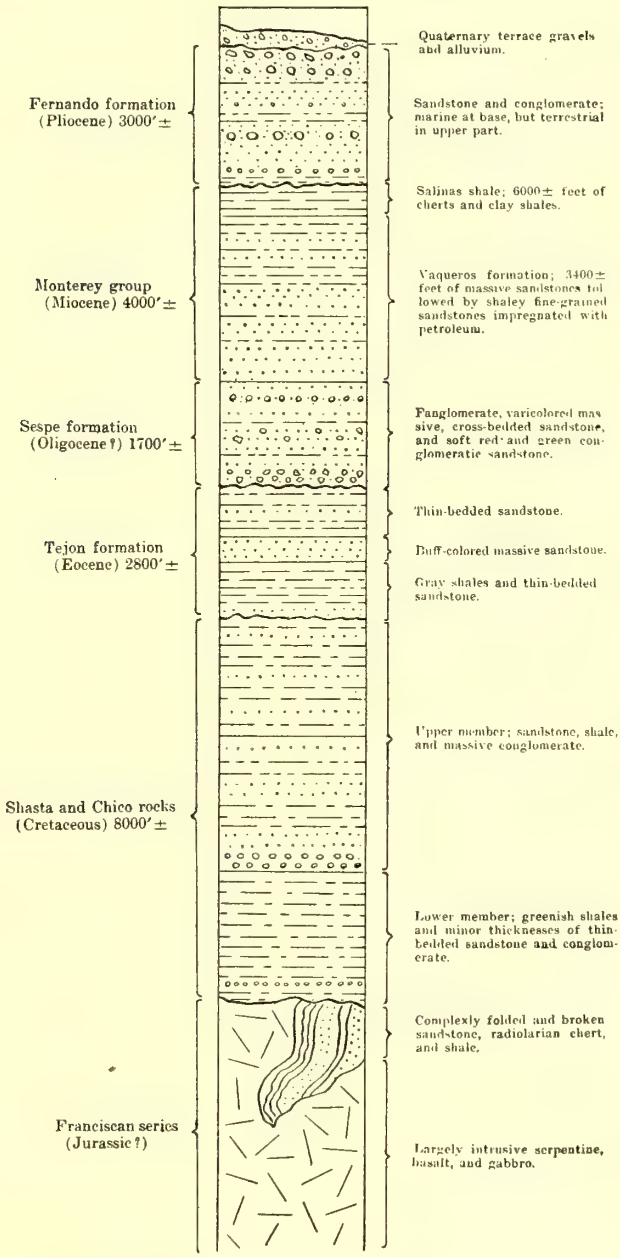


Fig. 2. Columnar section of strata exposed in the Santa Ynez River district, California.

STRATIGRAPHY

GENERAL FEATURES

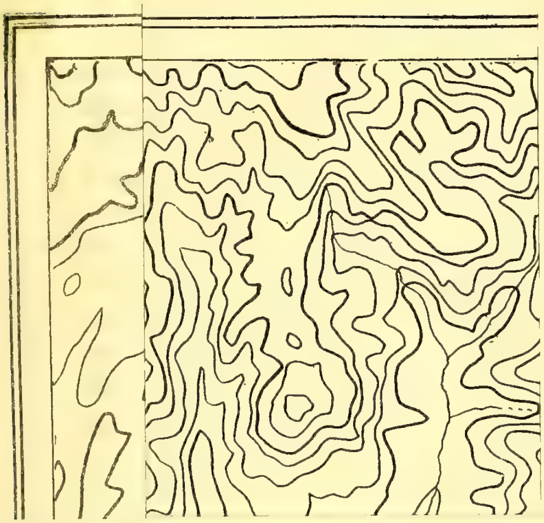
The formations exposed in the area are of sedimentary origin, with the exception of a few igneous rocks in the Franciscan series (Jurassic?). These rocks are the oldest in the district and are made up chiefly of sandstones, shales, and radiolarian cherts similar to those of the type section around San Francisco Bay. The Cretaceous is represented by conglomerates, sandstones, and shales which are in part of Knoxville (Lower Cretaceous) and Chico (Upper Cretaceous) age. The Tertiary comprises three groups of rocks. The Eocene is represented by the Meganos and Tejon formations (Middle and Upper Eocene), no Martinez (Lower Eocene) being recognized. Unconformably above the Tejon is the Sespe formation (Oligocene?) which is probably of continental origin. This is followed by the Monterey group (Miocene) in conformable sequence. The Fernando (Pliocene) formation overlies these with a marked unconformity; this is in the main of marine origin, but towards the upper part passes into fresh water clays, sandstones, and conglomerates which may be equivalent to the Paso Robles formation to the north. Pleistocene terrace deposits are common along the Santa Ynez River, and remnants of them are present as high as 1500 feet above the level of the river

JURASSIC(?) SYSTEM

Franciscan Series

The Franciscan series as exposed in the northern part of the Santa Ynez district occurs in two areas, one considerably larger than the other. The larger area extends along the southern slope of Little Pine Mountain and is a continuation of the Franciscan series mapped in the Santa Maria oil district.[1] Towards the east, near the big bend in the river, it becomes only a narrow strip marking the course of a fault.

[1] Arnold, Ralph, Geology and oil resources of the Santa Maria district, California, U. S. Geol. Surv. Bull. 322, 1907.



Base from U.S.G.S. topographic map, Southern California sheet No. 3

GEOLOGIC MAP OF A PART OF THE SANTA YNEZ RIVER DISTRICT, SANTA BARBARA COUNTY, CALIFORNIA

Contour interval 250 feet

Geology by W.S.W. Kew, and after R. Arnold, U.S.G.S. Bull. 321

The sedimentary strata[2] of the Franciscan series mainly consist of sandstones and radiolarian cherts with a minor amount of shale. The sandstones are massive, dark green in color, and arkosic. As a whole, they show a marked similarity to those typically exposed around San Francisco Bay. The cherts occur in relatively small patches, usually as inclusions in the igneous rock, though they have been observed as lenses in the sandstone. They show the characteristic banded structure and in some places are nodular. The shales occur mainly in a small area at the head of the middle branch of Redrock Cañon and are gray in color, rather soft, and contain numerous limestone nodules. They resemble the Knoxville shales, but when traced to the east, are seen to lie between beds of typical Franciscan rocks, such as the radiolarian cherts.

All the igneous rocks are of the basic type consisting mainly of basalt and serpentine with gradations into coarser grained diabase and gabbro. The basalts have the characteristic pillow structure so common in a similar rock of the San Francisco area. They are intrusive in the sandstone, shale, and chert, as dikes, sills, and small laccoliths, but have produced very little contact metamorphism. All the intrusions follow the general strike of the Franciscan rocks, that is, a northwesterly direction. On account of the great degree of disturbance caused by the intrusion of the igneous rocks and later deformation, no attempt was made to separate the different rocks on the map. The laccolithic structure is shown in the small area of basalt which forms the red rock from which the cañon of that name is taken. The upper surface of this rock mass is rounded while the lower side or bottom forms a steep almost overhanging cliff. Although on a very small scale, this body of rock resembles closely a typical laccolith. Serpentinization has not proceeded so far in some cases as in others, the less altered rock containing numerous large bastite crystals and some residual olivine. A serpentine, hydrometamorphosed to a silica-carbonate rock,[3] is exposed along the fault which parallels the Santa Ynez River. This is usually a brown hard mass which shows very little of the original serpentine. Cinnabar occurs in this and it has been mined in a small way for many years.

[2] A more detailed account of the sandstones and cherts occurring in this area may be found in two papers published by E. F. Davis, The Franciscan sandstone, Univ. Calif. Publ. Bull. Dept. Geol., vol. 11, pp. 1–44, 1918, and The radiolarian cherts of the Franciscan group, Univ. Calif. Publ. Bull. Dept. Geol., vol. 11, pp. 235–432, 1918.

[3] Knopf, Adolph, An alteration of serpentine, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pp. 425–430, 1906.

CRETACEOUS SYSTEM

Shasta and Chico Rocks

The Cretaceous strata resting unconformably upon the Franciscan series can be separated into two divisions: first, a lower series consisting mainly of shale interbedded with thin sandstones and a small amount of conglomerate; and secondly, an upper series of strata made up, for the most part, of sandstone with minor intercalations of shale and conglomerate. An unconformity between these two series is suggested by the presence of a heavy conglomerate at the base of the upper member, together with the fact that there is a sharp change in lithology from beds below the conglomerate to those lying above, and a slightly irregular contact between them. The lower beds are definitely known to be of Knoxville (Lower Cretaceous) age since *Aucella piochi* (Gabb) occurs abundantly in them. The upper beds may represent the Chico (Upper Cretaceous), though no fossils have been found to prove this statement.

In detail, the lower or shale strata consist of greenish black shale with minor amounts of interbedded sandstone and limestone. The sandstone is of a lighter color, fine to moderately coarse grained. The beds of limestone are quite impure, black to dark in color, and six to nine inches thick. About 300 feet stratigraphically above the base is a fifteen-foot bed of fine conglomerate, the pebbles of which average about one-half inch in diameter, though some are as large as a hen's egg. They are derived mainly from quartzite, black chert, and igneous rock. The upper fifty feet of the shale member consists of coarse sandstone formed of subangular grains of quartz, biotite, and serpentine. Marine fossils are present though indeterminable. All the bedded shaley strata are greatly folded and faulted, so that in many places the deformation resembles that occurring in the sedimentary beds of the Franciscan series.

The heavy conglomerate at the base of the upper series is somewhat lenticular in character, though it can be traced from the mouth of Blue Cañon along the ridge south of Gamusa Cañon; it again appears on the south slope of Little Pine Mountain immediately west of the Oso Cañon trail. A noticeable feature of this is that it occupies the same horizon as the Oakland conglomerate on the east side of San Francisco Bay. This conglomerate is made up of well rounded

boulders ranging in size up to a foot and a half in diameter. They consist of chert, trap, porphyries, granites, and rhyolites, and are cemented by a medium-grained, dark-gray sandstone. The Cretaceous strata lying above this conglomerate consist mainly of medium-grained, dark-green sandstone which weathers reddish. Immediately overlying the heavy conglomerate, the sandstone contains angular fragments of limy shale of a composition similar to the impure limestone in the Knoxville below the conglomerate. Thin layers of dark-green shale are interbedded with the sandstone, though the latter is predominant throughout this upper member.

TERTIARY SYSTEM

Eocene Series

Tejon Formation

In a publication by Eldridge and Arnold[4] relating to neighboring districts, the name Topatopa formation has been used to designate the Eocene strata lying above the Cretaceous and below the Sespe formation and continuous with the Eocene in the Santa Ynez district. Wherever exposed it has yielded typical Tejon and Meganos (Eocene) fossils and is therefore correlated with these formations, which are widespread over California, so that the name Topatopa becomes superfluous. At the time the field work for this report was done, the Meganos formation[5] had not been recognized. Later, in checking over the fauna, characteristic species of both the Tejon and the Meganos were found. As these formations have not been mapped separately, the Eocene as it occurs in this region will be considered as a whole and called the Tejon.

In the Santa Ynez River district, the Tejon forms the greater part of the Santa Ynez Mountains, and occupies a broad area immediately north of the Santa Ynez River east of Loma Alta. Its relation to the Cretaceous in this region is not clear, as in no place are the two in contact except on the south slope of Little Pine Mountain, where beds of doubtful Tejon age rest unconformably upon the Cretaceous.

A typical section of the Tejon as seen on the west side of Oso Creek consists of about 2800 feet of shales and sandstones with minor

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4 Eldridge, Geo. H. and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California, U. S. Geol. Surv. Bull. 309, 1907.

5 Clark, Bruce L., Meganos group, a newly recognized division in the Eocene of California, Geol. Soc. Am. Bull., vol. 29, pp. 281–296, June, 1918.

amounts of limestone and conglomerate. A hard calcareous basal sandstone rests immediately upon the Franciscan series. It is locally an impure limestone, and in places conglomeratic, the pebbles being derived mainly from the Franciscan rocks and ranging in size up to four inches in diameter. Upon this basal portion are about 1400 feet of bluish-gray shales, which weather readily into a fine clay soil forming low rounded hills and saddles on the ridges. Interbedded with this shale are layers of micaceous, rather coarse-grained sandstone, usually about an inch thick. These weather out of the shale and remain as thin flags on the surface. The following fossils, which show that it is of unmistakable Tejon and Meganos age, have been obtained within this shaley member:

Fossils from the Eocene

	3503	3504	2308	3505	3506	3507	3508	3509	3510
Schizaster, cf. diabloensis Kew	....	....	....	×	....	....	....	....	×
Leda, sp.	....	....	....	....	....	....	×	....	....
Ostrea, cf. idreaensis Gabb	....	....	....	....	....	×	....	....	....
Macrocallista conradiana (Gabb)	....	....	....	....	....	....	....	×	....
Meretrix hornii Gabb	....	....	....	....	....	....	....	×	....
Modiolus ornatus (Gabb)	....	....	....	....	....	×	×	....	....
Tellina remondii Gabb	....	....	....	....	....	×	....	....	....
Venericardia planicosta hornii (Gabb)	....	....	....	....	....	....	....	×	....
Amauropsis alveata (Conrad)	....	×	....	....	....	×	....	×	....
Nyctilochus whitneyi (Gabb)	....	....	....	....	....	×	....	....	....
Psammobia, cf. hornii (Gabb)	....	....	....	....	....	×	....	....	....
Surcula io (Gabb)	....	....	....	....	....	×	....	....	....
Turris suturalis(?) (Cooper)	....	....	....	....	....	....	....	×	....
Turritella andersoni Dickerson	....	....	×	....	×	....	×	....	....
Turritella, sp.	....	....	×	....	....	....	....	....	....
Turritella uvasana Conrad	×	×	....	....	×	×	....	×	....

3503. East side of Loma Alta mountain at head of two large cañons extending west from Redrock Cañon.
3504. In Oso Creek, just south of the narrows; in muddy sandstone between massive brown shales and bluff white sandstone.
2308. In west branch of Redrock cañon and about three-quarters of a mile northwest of their juncture.
3505. Santa Ynez Mountains in gray shale near steep pitch close to top of the Arroyo Burro trail.
3506. Santa Ynez Mountains on the Ridge trail in saddle west of Arroyo Burro trail.
3507. East side of Oso Creek in second cañon north of mouth.
3508. On west side of Paradise Cañon near its mouth; in dark greenish-gray shales.
3509. In Lewis Cañon immediately above falls; in hard bluish sandstone.
3510. In Oso Cañon about two miles north of mouth; in soft sandstone about 200 feet stratigraphically above bluff light-tan sandstone.

North of the river, these shales grade up into fine-grained, thin-bedded sandstone, upon which rests the massive buff to light-gray

sandstone so characteristic of the Tejon throughout the State. It usually forms bluffs and for this reason this lithologic member is often referred to as the "bluff sandstone." Its thickness here is about 500 feet. West of Oso Creek the bluff sandstone lies in a shallow syncline and forms vertical cliffs equal in height to its thickness. Another feature of the bluff sandstone is its cavernous weathering and nodular appearance. The character of the sandstone is that of a beach sand and for the most part is composed of medium-sized to coarse quartz grains. It is clean, well sorted, and in some places cross-bedded. A thin-bedded, fine-grained, easily weathered, buff to brownish colored sandstone about 1350 feet thick, containing minor amounts of clay shale, overlies the bluff sandstone. The only exposure of this member within the area mapped is located in the axis of the syncline west of Oso Creek, where it has been preserved from erosion.

In the Santa Ynez Mountains within the area studied, the Eocene section consists of about 14,000 feet of strata which is far thicker than the section west of Oso Creek. Arnold[6] measured a section east of Summerland which is over 8700 feet thick, not including the basal beds. The lowest beds exposed in this region are massive hard, brown, well-indurated sandstone, at the base of which is a heavy layer of conglomerate about 150 feet thick, made up mainly of quartzite boulders. This conglomerate is followed by a thin series of soft brown sandstone, which grades up into the green shale similar to that in the Oso Creek section, but harder and of a darker shade. The shale member here as in the latter place is overlain by the massive brownish bluff sandstone which forms the greater part of the Santa Ynez Mountains from La Cumbre Peak west to San Marcos Pass and beyond. This section is well shown on the Cold Spring trail and Arroyo Burro trail from Santa Barbara to the Santa Ynez River. The upper soft sandstone is absent from the Santa Ynez Mountains section. As a whole, the Tejon formation corresponds to that given by Eldridge and Arnold[7] for the Topatopa formation occurring in the range of mountains of that name in Ventura County. The lower part, consisting of about 2000 feet of "excessively hard, submassive sandstones and quartzites" in the Topatopa Mountains, is not represented by so great a thickness in the Santa Ynez Mountains, but this may be due to the fact that the lower beds are cut out by the Santa Ynez fault.

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[6] Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, California, U. S. Geol. Surv. Bull. 321, p. 22, 1907.

[7] *Op. cit.*

Oligocene (?) Series

Sespe Formation

Considerable variation in thickness of the Sespe in this district is shown from one locality to another. As a whole, it closely corresponds to the Sespe so well developed in Ventura County, and to the Pato red member of the Vaqueros described by English[8] in the Cuyama Valley district. It rests unconformably upon the Tejon group, but is conformable with the Vaqueros formation of the Monterey group, so it is thought probable that in this region no deformative movements took place between deposition of the Sespe formation and the Monterey group.

The Sespe in this district is best represented in the Santa Ynez Mountains, where it occurs in a syncline which extends from the mouth of Paradise Cañon to the Painted Cave east of San Marcos Pass. Another area lies just south of the Santa Ynez River near Mateo Cañon, and is separated from the Tejon by the Santa Ynez fault. The formation consists of 1700 feet of fanglomerates, cross-bedded sandstones, and minor amounts of shale and limestone. All the coarse material is rather highly colored, being either red, green, or yellow. In more detail the section here has at its base about forty feet of fanglomerate composed of angular fragments derived mainly from the Franciscan rocks. The greater part of the fragments, composed chiefly of the basic igneous rocks, range in size up to fourteen inches in diameter. Radiolarian chert is also a common material and its fragments are more angular than the others, due probably to their greater hardness. The matrix consists of rather coarse unsorted grains of the greenish basic igneous material. Above this fanglomerate are cross-bedded sandstones interbedded with softer layers. The sandstone is well sorted, clean, and shows well developed cross-bedding. The colors are also highly variegated, being in some instances purple with light yellow bands, or greenish with yellow or red streaks. Above these varicolored sandstones are softer red and green sandstones within which are a few thin layers of a bluish gray impure limestone.

North of the Santa Ynez River, the Sespe is much thinner, and appears to grade into the overlying fossiliferous coarse lower beds of the Vaqueros sandstone. It consists of the usual red fanglomerate

[8] English, W. A., Geology and oil prospects of Cuyama Valley, California, U. S. Geol. Surv. Bull. 621, pp. 191–215, 1916.

beds at the base, followed by other red and green sandstones, for the most part unsorted and slightly conglomeratic. The exposures of the Sespe north of the river are on the hill immediately east of Oso Creek, and on the east slope of Loma Alta.

No fossils have been found in the Sespe in the Santa Ynez district, and this fact, together with its lithologic character, strongly suggests that the greater part of the strata accumulated under arid conditions in basins surrounded by steep slopes composed of Franciscan rocks. The marked difference in thickness between the sections of opposite sides of the river may be accounted for in that the surface of deposition was irregular, which did not allow so great an accumulation of detritus in one place as in another. Regarding the age of the Sespe, no definite evidence is obtained from the sections studied in this district other than that it is post-Tejon and pre-Vaqueros, but it has generally been considered to be Oligocene.

Miocene Series

Monterey Group

General features.—In the Santa Ynez River district, the Monterey group is made up of four lithologic phases: (1) a lower, rather coarse sandstone containing the *Turritella inezana* fauna in its lower beds, and the *Turritella ocoyana* fauna in the upper part; (2) muddy sandstones, locally nodular, more shaley and enclosing impure limestone lenses; (3) a thin series of cream-colored clay shales containing an abundance of fish scales; (4) an upper zone composed of calcareous and siliceous cherty shales of the type which is so characteristic of the Monterey group over California. The first two are included with the Vaqueros sandstone member of the Monterey group, while the latter two members have been mapped as the Salinas shale[9] formation of the same group, a name recently adopted by the U. S. Geological Survey for these beds in Monterey County.

Vaqueros sandstone.—Both faunal zones of the Vaqueros, the *Turritella inezana* and *T. ocoyana* zones are represented, though the former was found only in the west fork of Blue Cañon. At this place, stratigraphic relations have been obscured by faulting. A fauna, in which *Pecten magnolia* and *Turritella inezana* are abundant, is present in

[9] English, W. A., Geology and oil prospects of the Salinas Valley–Parkfield area, Cal., U. S. Geol. Surv. Bull. 691–H., 1916.

beds of rather coarse greenish sandstones often conglomeratic, ill sorted, and cemented by a fine muddy sandstone. Where the Vaqueros rests upon the Sespe, as on the east side of Oso Cañon, Loma Alta, and in the vicinity of Mateo Creek, no *Turritella inezana* fauna was obtained, and the lowest beds contained *Turritella ocoyana.* Moreover, the Vaqueros consisting of coarse brownish sandstone, somewhat conglomeratic in places, grades down into the underlying Sespe with no indication of an unconformity.

The usual lithologic section of the Vaqueros consists of a heavy fossiliferous conglomerate at the base, followed by coarse gray to brown massive sandstones, which weather out into prominent strike ridges. This type of sandstone is a characteristic feature of the region on the south side of the Santa Ynez River above the Los Prietos ranger station, and as far east as the Cold Spring trail. Near the top of these sandstones, a twenty-foot bed of impure light gray to nearly white limestone may be traced from east of Blue Cañon to Oso Creek. It also forms a prominent feature in the syncline which lies immediately north of the Santa Ynez River in the vicinity of Mono Creek. The following fauna has been obtained from this limestone:

Cassidulus (Rhynchopygus) ynezanus Kew (Ms.)
Cassidulus (Rhynchopygus) ellipticus Kew (Ms.)
Scutella, cf. merriami Arnold
Pecten, sp.
Spiroglyphus, sp.
Ostrea, sp.
Turritella ocoyana Conrad
Terebratalia kennedyi Dall

Above the massive sandstones, sandy shales predominate, with interbedded layers of nodular muddy sandstones containing a *Turritella ocoyana* fauna. These shales weather bluish on the surface, but on fresh fractures the color is black, due to their impregnation by petroleum. The main body of these petroliferous shales is located in the Santa Ynez River east of Mateo Cañon. Where these strata are not bituminous, the color is usually a light orange or yellow. They are quite soft, and characterized by lenses and nodules of calcareous fine-grained sandstone which contain a *Turritella ocoyana* fauna.

Salinas shale.—No sharp line can be drawn between the Salinas shale and the Vaqueros, though the change in rocks is striking. The lower part of the Salinas shale is characterized by white clay

strata which contain an abundance of fish scales. The shale has the peculiarity of being extremely well bedded, and on weathering breaks up into very thin plates. The upper portion consists mainly of thin rhythmically banded cherty and calcareous beds. A gradual transition from the lower phase takes place, as the cherty type is found interbedded with the clay shales. The calcareous bands in the shale give off a strong fetid odor when struck with a hammer. The best exposures of this section are seen on Little Pine Mountain, Loma Alta, east of Oso Cañon, and on the hill immediately behind the ranger station on Mono Creek. At the latter locality the thickness of the Salinas shale is about 600 feet.

Pliocene Series

Fernando Formation

The Fernando occupies a synclinal basin on the north side of the Santa Ynez River, extending from the large area in the Santa Maria district as far east as Redrock Creek. The great accumulation of deposits representing 3000 feet of shales, sandstones, and conglomerates described by Arnold[10] from the Santa Maria district is partly represented in the area here described. At Redrock Cañon the beds aggregate about 1000 feet, but become thicker to the west.

A light gray biogenic shale lying above the Salinas shale probably is the base of the Fernando, since it conforms to the later folding. It closely resembles some of the Salinas shale beds but differs in that it is much softer. Overlying this is a series of fossiliferous sandstones which, in their lower part, are conglomeratic. The pebbles in the conglomerate have been derived almost entirely from the chert of the Salinas shale. Above this, a softer tan and gray sandstone containing *Dendraster ashleyi* var. *inezanus* Kew (Ms.), grades up into a hard gray sandstone containing this same echinoid and also *Nassa californica* Conrad. In the small syncline within the main synclinal trough, beds of continental origin are found. These consist of reddish, buff colored muds and sands interbedded with layers of unsorted conglomerate. Teeth and limb bones of rodents were obtained from the clays and sands of these beds. Farther to the west, these deposits become thicker and more extensive. Their lithologic nature, together with the

[10] Arnold, Ralph, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California, U. S. Geol. Surv. Bull. 322, 1907.

fact that they rest upon beds of upper Fernando age, suggests that they may be correlated with the Paso Robles formation, which is well developed in the Salinas Valley. Arnold[11] mentions similar land-laid deposits from the Santa Maria district and says that they are probably the equivalent of the Paso Robles formation. None of the beds in this district are of Miocene age, and the faunal evidence indicates that they are upper Pliocene and do not represent the lower Fernando occurring in the Elsmere Cañon section of the Santa Clara Valley.

QUATERNARY SYSTEM

Terrace Deposits

At least six distinct deposits of terrace material are present along the Santa Ynez River, the highest one being at an elevation of 1500 feet. Their extent is not large enough to show on the map and the deposits forming any one terrace are never over 100 feet thick. They are composed of unsorted material, usually unconsolidated, which has been washed down from the higher areas at their rear. Where made up of the diatomaceous shale, the material is much finer than when derived from the hard Tejon or Cretaceous rocks, and huge boulders several feet in diameter are a common occurrence in the beds that are well exposed in the vicinity of Mateo Potrero.

STRUCTURE

GENERAL FEATURES

The structure of the California Coast Ranges is relatively complex, but in general, the folding and faulting has a definite northwest trend which is reflected topographically. In the Santa Ynez River district, the San Rafael Mountains conform to this general habit, whereas the Santa Ynez Mountains are anomalous in that their trend is almost east-west. The general structure of the latter range is that of an anticline, dislocated on the north side by the Santa Ynez fault, the faulting having occurred in post-Fernando time. In the vicinity of San Marcos Pass, the fold is comparatively simple, whereas on the south side of the range, east of La Cumbre Peak, the strata are overturned to the south. Another set of folds within the range has a northwest strike, and probably was formed prior to the general anticlinal folding of the mountains but at the same time as the

[11] Arnold, Ralph, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California, U. S. Geol. Surv. Bull. 322, p. 55, 1907.

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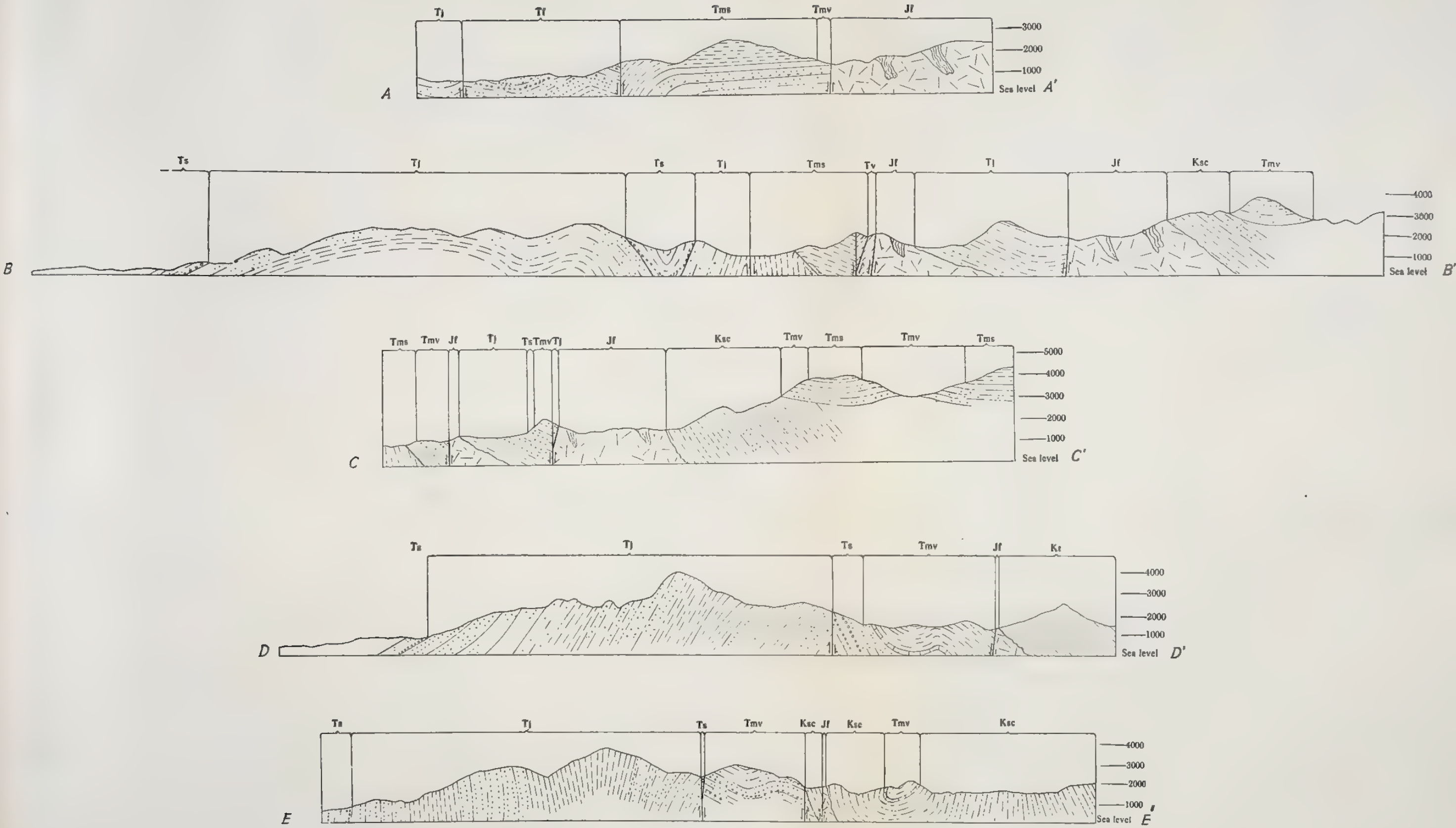

STRUCTURE SECTIONS IN SANTA YNEZ RIVER DISTRICT, CALIFORNIA

For lines of sections see Plate 1

EXPLANATION.—*Tf*, Fernando formation; *Tms*, Salinas shale; *Tmv*, Vaqueros sandstone; *Ts*, Sespe formation; *Tj*, Tejon group; *Ksc*, Shasta and Chico rocks; *Jf*, Franciscan series.

deformation of the San Rafael Mountains. Although only a small part of the San Rafael Mountains was examined, the Little Pine Mountain vicinity indicates a northeastward dipping series of rocks ranging in age from Jurassic(?) to the end of the Miocene. These are faulted on the south side by the Little Pine fault which is of pre-Fernando age. In the area between these two faults is a belt of acutely folded rocks, in greater part of Miocene age, though Franciscan and Tejon strata appear between Oso and Redrock creeks. These three areas constitute separate structural belts which will be described more in detail.

Three large faults cut this district in an east-west direction, the longest being the Santa Ynez fault, which follows the north side of the Santa Ynez Range and has evidently controlled the corrasion of the river. The Redrock fault is comparatively short, but has brought the Franciscan rocks up against the beds of the Monterey group. North of this fault, the Little Pine fault extends along the foot of Little Pine Mountain and continues to the east, following the Santa Ynez River Cañon to Blue Cañon. The age of the first is post-Pliocene, while the latter two are pre-Pliocene. Several cross faults are present in this region, which will be discussed in the section on detailed structure.

DETAILED STRUCTURE

Little Pine Mountain Area

This area includes all the territory lying north of the Little Pine fault and extending east to Agua Caliente Creek. Little Pine Mountain is composed of a block of northward dipping Franciscan and Cretaceous strata overlain by beds belonging to the Monterey group. The structure of the Franciscan series is complex and obscure, due to the great amount of deformation chiefly caused by the large intrusions of igneous rocks. In general the sandstones and cherts strike in a northwesterly direction, and the igneous rocks are intruded along their bedding planes. The Cretaceous dips on the average about forty degrees to the north, except in the eastern part of the area, where the strata have been so acutely folded that the structure is obscure. Lying upon the Cretaceous are two relatively small synclinal areas of Miocene rocks. The eastern one lies directly north of the Santa Ynez River and crosses Mono Creek at the ranger's cabin. The Monterey group is here considerably less folded than the underlying Cretaceous sandstones and shales, and the syncline pitches east about five degrees and gradually broadens. Near the junction of Blue Cañon with the

Santa Ynez River the fold is cut by a cross fault, beyond which it is materially narrowed, though the syncline can be traced considerably farther to the east. The other syncline forms the top of Little Pine Mountain. It is quite shallow, as the Salinas shale lies nearly flat at the summit. The northward extent of these rocks has not been traced. The most important structure related to this area is the Little Pine fault, which limits it on the south. The fault is remarkably straight and topography characteristic of faulting is common along it. The trace of the fault is usually distinct as it separates the soft Tejon shales from the Franciscan in some places, and in others, the Knoxville shales from the Monterey group, being thus a noticeable feature in the topography of the country. The altered serpentine in which the cinnabar occurs is present only on this fault zone. The rock is somewhat harder than the adjacent strata, and it weathers into a rather prominent "reef" along the fault. The dip of the fault plane is nearly vertical, though a dip of eighty degrees to the south was noticed in a few places. A minor cross fault dislocates this main fracture in the cañon north of the big bend in the Santa Ynez River. To the west of Redrock Creek, the fault is overlapped by the Fernando strata, thus placing its age as pre-Fernando. In its eastward extension, it is cut off by a cross fault at the mouth of Blue Cañon. At this point it is quite close to the Santa Ynez fault, the two being about a mile apart. This indicates that structural lines of both the San Rafael and Sana Ynez mountains are convergent in this region.

Santa Ynez River Area

The most highly folded Tertiary strata in this district lie within the belt of formations that trends in a northwest direction along the course of the Santa Ynez River. It is about a mile wide at its eastern end, where it is cut off by a cross fault near the mouth of Blue Cañon; to the west it broadens until, at Loma Alta, the width is somewhat more than five miles. Complicated folding and faulting are a characteristic of the area. The most interesting piece of structure is that of Loma Alta and the adjacent region to the east, including the high hill east of Oso Creek. Loma Alta is made up of a series of strata ranging in age from the Tejon through the Monterey group, the oldest of which rest upon the Franciscan series. The essential structure is anticlinal, broken by the Redrock fault along the eastern end of its axis. Although the beds are fractured close to the main ridge of Loma Alta, the fault does not pass through the moun-

tain. The shales and cherts of the Monterey group forming this part of Loma Alta have a comparatively simple attitude, dipping to the west and forming the nose of a steeply pitching anticline. To the east of this main ridge, erosion has produced a cirque-like excavation which has exposed the underlying rocks of the Franciscan and Tejon series that form the north limb of the anticline in Redrock Cañon. The south flank of the fold has been faulted down, so that the strata of the Monterey group have been thrown against the Franciscan. The Monterey beds dip to the west with a north strike near the summit of Loma Alta and then swing to the southeast and east, forming a strike ridge on the south side of the mountain. The beds near Redrock Creek become steeply tilted until they are slightly overturned in the bottom of Redrock Cañon. All the lower part of the Monterey, including the heavy bedded sandstones, has been faulted out, leaving only a thin strip of the finer grained upper members. In contrast to the steeply tilted beds of the south side, the north limb of this anticline is made up of comparatively gently dipping Tejon strata resting unconformably upon the Franciscan rocks. On Loma Alta Mountain, the Tejon is overlain by the Sespe formation and Monterey group. The whole series is terminated on the north by the Little Pine fault, which cuts across these beds in some places at right angles to their strike.

The more elevated region between Oso and Redrock creeks and that east of Oso Cañon is occupied by an eastward pitching syncline, which is the complementary fold to the Loma Alta anticline described above. Both the Eocene and Miocene rocks are involved in the folding, the latter being represented only east of Oso Creek. The massive bluff sandstone of the Tejon stands out prominently west of Oso Creek as a shallow trough which forms cliffs about five hundred feet high along its margin. The Little Pine fault on the north side cuts obliquely the different members of the series so that only a small part of the bluff sandstone, considerably broken, remains at Oso Cañon. Although the axis of the syncline is not traversed by the Little Pine fault, nevertheless faulting has taken place along it, so that the steeply tilted and broken remnant of the north limb lies against the gently dipping southern part of the Tejon and Miocene strata. The bluff sandstones as exposed here were continuous at one time with the same member of the Tejon which is present on the west side of Redrock Cañon.

Along the Santa Ynez River itself, the structures are more complex than in any other part of the district. South of Loma Alta, the

Fernando has been faulted down against the Salinas shale and folded into a syncline and anticline. These folds are closely compressed in Redrock Cañon, but flatten out to the west so that the dip of the beds is not over twenty degrees. East of Redrock Cañon complexly contorted and faulted strata prevail. The Monterey group extending east from the Loma Alta area is usually overturned and complicated by numerous small faults. The Redrock fault east of Loma Alta ends at a cross fault, which occurs just west of the big bend in the Santa Ynez River. East of this bend the strata show more definite structure; also a more continuous section from the Sespe through a greater part of the Monterey is exposed. Two folds, a syncline and an anticline which pitch to the west may be traced as far east as the Cold Spring trail.

The Santa Ynez fault which forms the southern limit for this area is of especial interest in that it represents one of the latest periods of disturbance in this region. This fault traverses the entire width of the Santa Ynez district in a direction slightly south of east and is approximately parallel with the axis of the Santa Ynez Range. It separates the Eocene strata forming the major part of the mountains from the Miocene and Pliocene rocks on the north. Evidence as to the dip of the fault plane is not usually available, but, wherever seen, the dip is approximately vertical. The fault trace is marked by straight cañons and saddles in ridges. This is strikingly shown in Blue Cañon and on the divide at the head of its west branch. The fault is by far the largest in the district and probably extends farther to the east up Blue Cañon, though it has not been followed beyond the limits of this district.

Santa Ynez Mountans Area

The Santa Ynez Mountains are characterized by two sets of folding which probably occurred at different periods. The earlier set is represented by the northwesterly striking folds immediately east of San Marcos Pass. The largest of these is a syncline whose axis follows closely the trend of Paradise Cañon. Infolded with the Tejon rocks is about 1700 feet of the Sespe formation. To the west of this fold an anticline and syncline parallel this fold on the west. They are considerably shallower, so that the Sespe formation has been eroded from the syncline. All these folds are cut off obliquely at the north by the Santa Ynez fault.

The folding of the later period is shown in the main structure of the mountains, namely, the Santa Ynez anticline. This deformative movement has continued to comparatively recent times, for late Pliocene strata of marine origin along the beach at Santa Barbara have been tilted to an angle of forty-five degrees and raised considerably above sea level. The axis of the fold extends approximately along the crest of the range, but east of the San Marcos Pass it swings slightly northward, and passing to the north of La Cumbre Peak is terminated by the Santa Ynez fault. To the east of La Cumbre in this district the north limb of the anticline has been faulted out, and the Miocene beds have been let down against the Tejon along the axis of the fold. Near San Marcos Pass, the fold is broad, the gently dipping massive sandstones forming the slopes of the mountain in this vicinity. Farther to the east, the strata become tilted to a much greater angle, and east of La Cumbre Peak the major part of the beds constituting the south limb of the anticline is overturned. The foothills of the range are made up of post-Eocene formations resting upon the Tejon. Arnold[12] has described the geology and structure of the mountains in the vicinity of Summerland, which is similar to that in the western part of the district.

CONCLUSIONS

Although the stratigraphy of the Santa Ynez district is similar to that usually occurring throughout the California Coast Ranges, a few observations of interest should be emphasized. (1) The Sespe formation and Monterey group in the Santa Ynez district were laid down without the interruption of deformative movements, during which time the sea transgressed upon the land; (2) at least two periods of folding and faulting have taken place since the Miocene: the first before the deposition of the Fernando formation, the second after the Fernando and probably continuing into Recent time; (3) the Santa Ynez Mountains are genetically as well as geographically distinct from the San Rafael Mountains, the former having been formed during the later diastrophic movements (post-Pliocene), and the latter during the earlier ones (pre-Pliocene), in which the forces acted in a different direction.

Transmitted April 23, 1919.

[12] Arnold, Ralph, Geology and oil resources of the Summerland district, California, U. S. Geol. Surv. Bull. 321.

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CRETACEOUS AND CENOZOIC ECHINOIDEA OF THE PACIFIC COAST OF NORTH AMERICA

BY
WILLIAM S. W. KEW

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CONTENTS

INTRODUCTION

The echinoids have been recognized as a group of great importance in the palaeontology and stratigraphy of the West Coast Cretaceous and Tertiary formations, and their worth is being realized as more detailed faunal studies are made and as more exact stratigraphic work is done. In general, the echinoids are of limited geologic range, as their evolution proceeds rapidly. The species are easily recognized, the individuals are often very abundant, and their state of preservation is commonly better than that of associated invertebrate forms. These factors combined make the group of exceptional interest for biologic studies, and of unusual importance in geologic correlation and age determinations.

The first study of the Cenozoic echinoids of the Pacific Coast is that of Conrad (1856), who described the genus *Astrodapsis* and the species *A. antiselli.* Rémond (1863) recognized four important species. No further contribution was made until Merriam (1898–1899) took up the study of the evolution and geologic range of several species. From this time on, the value of the group as an aid to stratigraphy was realized, and during the decade between 1900 and 1910 valuable contributions to the literature were made by Arnold (1907–1909), Pack (1909), and Weaver (1908). A recent contribution of major importance is that of Clark and Twitchell in their monograph, the *Mesozoic and Cenozoic Echinodermata of the United States,* which includes descriptions of many California species.

In beginning the present work it was intended to assemble the echinoids of California and adjacent regions in order to make the available material more useful to the palaeontologist and the field geologist. As the work progressed it became apparent that a considerable part of the fauna had not been described in earlier papers and that many of the described forms were in need of revision. It was, therefore, necessary to make a thorough revision of the whole echinoid fauna of the Pacific Coast in order to present a statement of the geologic range and evolutionary sequence of the species.

The first discussion in this paper deals with the geologic and geographic ranges, the relationships of the Pacific Coast echinoid faunas to those of other provinces, the climatic conditions indicated by the echinoid faunas, and the phylogeny of the most important genera; the second part comprises systematic descriptions of the

GEOLOGIC TIME SCALE FOR THE PACIFIC COAST

	Generalized Section of Coast Ranges of California	Mt. Diablo Region San Francisco Bay	Santa Cruz Mts.	Coalinga District	Salinas Valley-Parkfield District	Santa Maria District	Los Angeles-Ventura District	Generalized Section of Coast Ranges, of Oregon and Washington
Pleistocene	Upper San Pedro	Rodeo formation		Terrace	Terrace	Terrace	Terrace	
Pliocene	Upper Merced: San Pedro Pliocene San Diego formation ——? Lower Merced: Upper Etchegoin —Fernando Lower Etchegoin (Jacalitos)	Campan formation Siestan formation Pinole tuff Orinda formation	Santa Clara formation Merced Purisima	Tulare formation Upper Etchegoin Lower Etchegoin (Jacalitos)	Paso Robles Upper Etchegoin Lower Etchegoin (Jacalitos)	Fernando	Upper Fernando Lower Fernando	Merced Empire Wildcat series Montesano
Upper Miocene	San Pablo group Briones formation	San Pablo group Briones formation	"Santa Margarita" formation	"Santa Margarita" formation	"Santa Margarita" formation	"Santa Margarita" formation		
Lower Miocene	Monterey group (Turritella ocoyana) Vaqueros (Turritella ineziana)	Monterey group	Monterey shale Vaqueros	Monterey group (Turritella ocoyana)	Salinas shale Vaqueros	Monterey shale Vaqueros	Modelo (Puente) formation (Turritella ocoyana) Vaqueros (Turritella ineziana)	Monterey group
Oligocene	Sespe formation San Lorenzo series	San Lorenzo series Kirker formation San Ramon formation Markley formation	San Lorenzo Butano sandstone	Kreyenhagon shale		Sespe formation	Sespe formation	San Lorenzo series
Eocene	Tejon group Meganos group Martinez group	Tejon group Meganos group Martinez group	Eocene	Tejon group Meganos group Martinez group		Tejon group	Tejon group Meganos group Martinez group	Tejon group Meganos group
Cretaceous	Chico Horsetown Knoxville	Chico Knoxville	Chico Knoxville	Chico group	Knoxville and Chico rocks	Chico? Knoxville	Chico group	Chico Knoxville
Jurassic (?)	Franciscan series Granites and Metamorphics	Franciscan series	Franciscan series	Franciscan series	Franciscan series Granites and Metamorphics	Franciscan series	Granites and Metamorphics	Franciscan (?) series

known forms of the Pacific Coast of the United States, of Lower California, and of the Gulf of California province, of which eighty per cent are new. No fossil echinoids have been available from either Canada or Alaska, and the west coast of Lower California is represented by only two species; the meagerness of the known fauna in these regions is due in all probability to the lack of palaeontologic collecting.

During the four years in which the writer has been engaged in the study of the fossil Echinoidea of the Pacific Coast, research has been made possible by the large collections in the University of California, Leland Stanford Junior University, and the California Academy of Sciences. In each of the above institutions collecting is being carried on in the Cretaceous and Tertiary formations of California, which within the last few years has resulted in bringing together a large amount of material.

Acknowledgment is given here to the museums of these institutions for the generous use of the new forms which the writer has been privileged to describe.

To Professor John C. Merriam, whose ever ready advice and cooperation were of the greatest assistance in the preparation of this manuscript, it is the writer's pleasure to express his deepest gratitude. For further advice and criticism the author is indebted to Dr. Bruce L. Clark.

In the fall of 1914, through the kindness of Dr. F. A. Bather, the writer had the opportunity of studying the echinoderm collections in the British Museum of Natural History.

Many friends have contributed to the completion of this monograph, either by donating specimens or giving helpful suggestions and information. Among these are Professor James Perrin Smith of Stanford University, Dr. Roy E. Dickerson of the California Academy of Sciences, R. W. Pack and W. A. English of the U. S. Geological Survey, and R. C. Stoner and Dr. J. O. Nomland of the Geological Department of the Standard Oil Company of California. The photographing of the specimens was done by W. C. Mathews.

GEOLOGIC RANGE

In the discussion of the geologic range of the Pacific Coast echinoids it is found that the subject may be treated under two topics: first, the range of the genera, and, second, the range of each species in detail. The first is of major importance in the west coast province, especially during the Tertiary period, for it is only within certain definite time intervals that these genera occur. This is graphically shown by figure 1. In treating the second topic it is not necessary to discuss each species separately, and their stratigraphic position can be expressed better in tabulated form.

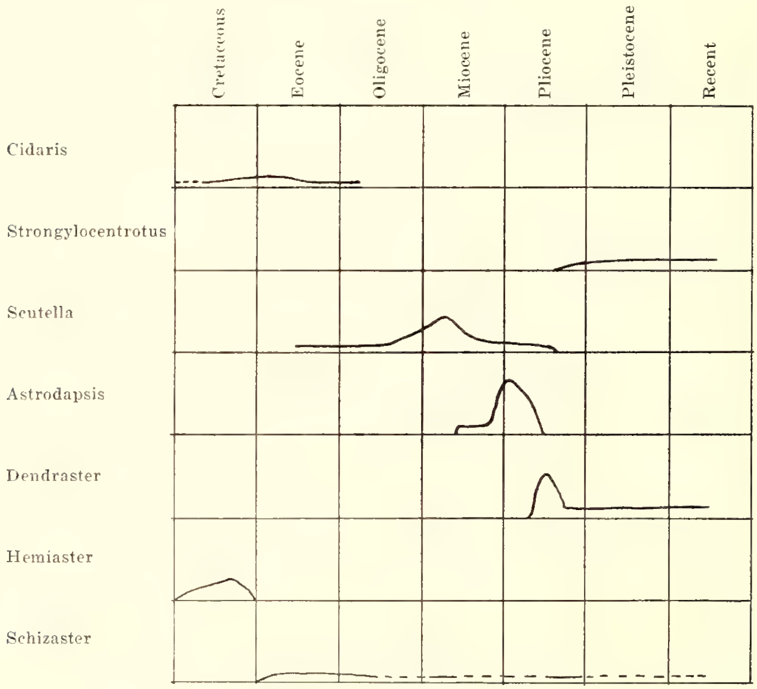

Fig. 1. Geologic ranges of the more important genera of Pacific Coast echinoids.

Explanation.—Horizontal extension of curve represents geologic time. The curve with the highest vertical extension indicates the genus with greatest number of species and probably the dominant genus at that time. The broken line indicates incompleteness in the fossil record, and the probable range of the genus.

The Cretaceous forms are mainly of the cassidulid and spatangid types. *Hemiaster* seems to be the most characteristic form, no species of this genus being reported from any later age. One species of *Catopygus(?)* is present in the Upper Cretaceous, but this genus is not confined to this horizon.

The Spatangidae continue to be the dominant family in the Eocene, the genus *Schizaster* making its appearance at this time and being the most numerous throughout this period. *Rhynchopygus, Spatangus,* and *Cidaris* are also found, but sparingly. Scutellid forms occur in the Tejon group in both California and Oregon, though the ones from the former locality are indeterminable. The occurrence of *Scutella* in the Eocene is important in that it marks the first appearance of this family on the west coast.

The general character of the fauna of the Oligocene remains the same as in the Eocene, the spatangids being represented by the genus *Schizaster*. The genus *Scutaster* is the only scutellid which has been reported so far and known to be characteristic of the Oligocene in California, though *Scutella newcombei* Kew is present in the Sooke beds of Puget Sound and *S. blancoensis* Kew from Oregon.

The fauna of the Neocene consists almost wholly of scutellid forms, of which three genera stand out more prominently than any others. Each has a definite range and these overlap one another but little. The Lower Miocene echinoids are composed almost entirely of Scutellidae, only two species of *Cassidulus* and a single fragment of a spatangoid having been found. The different character of the fauna is probably due to the change in sedimentary conditions from those hitherto existing. During the earlier periods the deposits mainly consisted of fine-grained sandstone or shale, whereas in the early part of the Miocene the coarse type of sediments point to the fact that shallow water prevailed, in which the littoral forms such as scutellas developed and not the deeper water spatangid types. Another feature of the Miocene, and of the Pliocene also, is the marked rise in the number of species and individuals of this group. In both the Vaqueros formation or *Turritella ineziana* zone and the *T. ocoyana* zone of the Monterey group, Lower and Middle Miocene, there are at least seven different species or varieties, which represent the maximum development of *Scutella*. Following the dominance of *Scutella* the genus *Astrodapsis* makes its appearance. Although this genus was present before the extinction of *Scutella*, the greatest development of *Astrodapsis* was during the decline of the former, that is, in the uppermost

Miocene (upper part of the San Pablo group). After this period the reduction in the number of species was rapid; we have a decrease from at least fifteen forms in this formation to seven in the Pliocene, Lower Etchegoin (Jacalitos) formation. The next important genus to make its appearance is *Dendraster,* which invaded California seas in Lower Pliocene time, during the decline of Astrodapsis. The Upper Pliocene formations show the greatest development of the dendrasters, when at least twelve forms are represented. After the close of the Pliocene there is a rapid decline in the number of species until at present the widely distributed *D. excentricus* (Eschscholtz) is the only living species.

Of the less important genera, *Sismondia(?)* is reported by Twitchell to occur in the Upper Etchegoin formation; *Strongylocentrotus* is not found earlier than the Pliocene of Southern California and is very abundant in the Pleistocene along the Pacific Coast at present; *Rhynchopygus* is present in the Lower Miocene, continuing from the Eocene; *Mellita* occurs in the Pleistocene Upper San Pedro formation, but is now extinct on the coast of California; and *Tripneustes, Clypeaster,* and *Encope* are found in the Pliocene, Carrizo Creek formation, but belong to the Gulf of California province, which contains a fauna distinct from that of the Pacific Coast proper.

GEOGRAPHIC DISTRIBUTION

Although a great mass of sediments was deposited during the Cretaceous, which are preserved to us in a large part today, we find in them an extraordinary lack of fossil echinoids. This fact is still more striking, considering the large collections of invertebrates that have been made from the same formations in many parts of the state. Very little is known about the Lower Cretaceous echinoderms, for the Tesla district of Middle California is the only locality in which any have been collected up to the present time. In the Upper Cretaceous they were more numerous, both in species and individuals, and in geographic distribution are known to have lived along the coast from the Santa Ana Mountains of Southern California to the northern part of the Sacramento Valley. *Hemiaster californicus* Clark has been found in both localities, indicating one of the most extensive ranges for any west coast echinoid. From the data con-

cerning the sea urchins of this period it may be concluded that they were not numerous, though they had a uniform distribution.

During the Eocene more or less the same condition prevailed, and, as in the latter period, the echinoderms were of wide distribution over California, the species *Schizaster lecontei* Merriam, *S. diabloensis* Kew, and *Spatangus pachecoensis* Pack occurring from Santa Barbara County to the San Francisco Bay region. Shallow water forms, such as *Scutella,* were absent from the southern part of the state, but were present sparingly in the vicinity of San Francisco and Oregon.

The Oligocene and more especially the Neocene, in marked contrast to the Cretaceous and Eocene, became favorable for harboring many shallow water forms. In the Oligocene *Scutaster andersoni* Pack, a littoral scutellid form, has a relatively wide distribution, being found in the southern end of the San Joaquin Valley and also in Contra Costa County. Although the number of species is large, the Lower Miocene fauna is peculiar in that the majority are confined to certain localities in the southern part of the state. Those having the widest geographic range are *Scutella merriami* (Anderson) and *S. norrisi* Pack, which are found in Orange County and in the Diablo Range as far north as the vicinity of Coalinga. The Upper Miocene fauna shows that special geographic subprovinces were present which continued through the Pliocene. Each subprovince contained a fauna which, in the aggregate, had forms that were specifically different from those of other subprovinces, yet a few species were common to all.

During the Miocene the California province as a whole may be divided into the following subprovinces: (1) Northern, including San Francisco Bay, Mount Diablo region, north to Puget Sound; (2) San Joaquin Valley; and (3) Outer Coast Ranges, which includes the Salinas Valley, Santa Maria, and Los Angeles districts. In all these *Astrodapsis tumidus* Rémond and *A. whitneyi* Rémond were common during Upper San Pablo (Santa Margarita) time. *A. major* Kew, occurring in the uppermost part of the San Pablo at Mount Diablo, is a species very closely allied to the *A. arnoldi* group, which is the most prevalent type in the lower part of the Etchegoin (Jacalitos) formation of the two southern subprovinces. *Dendraster arnoldi* Twitchell is another form common to the latter two formations in Fresno and Santa Cruz counties. In the Upper Etchegoin the fauna as a whole changes and the subprovinces seem even more distinct faunally than before. The San Francisco Bay area, which at this

time was characterized by *Calaster interlineatus* (Stimpson) and *C. oregonensis* (Clark) and its varieties, had no echinoderms in common with the other subprovinces. In the southern areas only three forms are found which extend across the Diablo Range. These are *D. gibbsii* (Rémond), common in the Coalinga region, which also occurs to the west in San Benito County, and *D. ashleyi* (Arnold) and *D. gibbsii* var. *humilis* Kew, which are found in the Coalinga district and in Santa Barbara County. Within the subprovinces themselves different localities possess slightly different forms, as is shown in the many subspecies of *A. arnoldi* (Pack), all of which are of approximately the same age. The above evidence seems to indicate that the fauna, though probably living in more or less connected subprovinces, shows marked evidence of an influence due to segregation under varying environmental and climatic conditions which has caused in large part at least, the dissimilarity in character of each fauna; conversely, it may be stated that the echinoderms quickly adapt themselves to different conditions.

During the Pliocene the Colorado desert in the vicinity of the Salton Sea and Imperial Valley existed as a separate province, in which the fauna was entirely unlike any other found in California. This was a distinctly warm water type, which bears a close resemblance to the Recent fauna of the west coast of Mexico, Central America, and the Gulf of California.

FAUNAL RELATIONS WITH OTHER PROVINCES

In the discussion of the relationships which the Pacific Coast fauna bears to that of other provinces it would be advisable to compare it with that of other North American provinces and those of Asia. Unfortunately, so little is known of the east Asiatic fauna that a comparison with this province is not feasible, but the provinces of central and eastern North America and of India can be satisfactorily contrasted. The west coast fauna described in this paper is for the most part of a type characteristic of temperate waters, except that of the Gulf of California, which is tropical. In the comparison of the faunas of the various provinces this fact must be kept in mind.

The Upper Cretaceous fauna of the west coast possesses only three genera in common with the interior and gulf provinces of North America. These are *Cidaris, Catopygus,* and *Hemiaster,* of which no

species are identical, though a few show close similarities. The Eocene fauna bears approximately the same relationship, having in common but four genera: *Cidaris, Scutella, Rhynchopygus,* and *Schizaster.* The eastern fauna is considerably larger, having nineteen more genera than the western. The Oligocene retains about the same relationship as the Eocene, but the comparatively meager fauna of the Pacific Coast does not permit a satisfactory comparison. In marked contrast to the former periods, the Miocene and Pliocene of the west coast possess the most abundant fauna of the temperate type. Only two genera, *Scutella* and *Schizaster,* are common to the fauna of the Gulf and Atlantic provinces. The western fauna at this time shows a great development of the genus *Scutella,* whereas the only eastern species is *Scutella aberti* Conrad, which is of an entirely different type from the western forms. Furthermore, the many species of *Dendraster* and *Astrodapsis,* forms not occurring on the Atlantic Coast, are especially abundant on the Pacific. On the other hand, genera such as *Laganum* and *Periarchus,* relatively abundant in the Gulf fauna at this time, are not present among the west coast fauna. During the Pleistocene some intermingling of the faunas took place since *Strongylocentrotus dröbachiensis* Müller and *Scutella parma* (Lamarck) are present on both of the northern coasts of North America.

The Indian Cretaceous fauna does not seem to have so intimate a relationship to the Pacific Coast fauna as does the interior and the Gulf provinces of North America. Although the same genera are common, the specific forms are not so closely allied. In the Eocene all of the genera of the west coast are present in the Indian fauna of this period, but none of the species are the same. Beginning with the Oligocene, the genera become more distinct, though such forms as *Rhynchopygus* and *Schizaster* continue to be common to both regions. On the California coast the Scutellidae is the dominant family, whereas the Indian fauna acquires a tropical aspect, having forms such as *Clypeaster* and *Breynia.*

The Carrizo Creek fauna, of the Gulf of California province, being of the tropical type can be compared to the Gulf of Mexico and Panama assemblages. Although the genera *Cidaris* and *Encope* are common to this and to the Pliocene fauna of the Gulf of Mexico province, it shows its closest resemblance to the Recent fauna of the Gulf of California, the species differing only very slightly.

In summarizing, it may be stated that the Cretaceous and Eocene faunas of the Pacific Coast province are not only closely related to

the interior and the Gulf provinces of the United States but also to that of India, though neither to the extent of identity of species. Of the two, the North American provinces are the more closely allied. During the Neocene the Pacific Coast region became faunally more distinct, which indicates that there was no intermigration of faunas either with the eastern part of the United States or with India.

CLIMATIC CONDITIONS INDICATED BY THE ECHINOID FAUNA

Climatic conditions probably exercised a marked control over the distribution of echinoids in past times, as at present, and from observations on the influence of temperature on the recent fauna, especially that of the littoral zone, some conclusions may be reached as to the previous ocean temperatures. Along the Pacific Coast *Dendraster excentricus* (Eschscholtz), one of the most common Recent littoral forms, has a geographic range from the Lower California coast to Bering Sea. The genus *Strongylocentrotus,* similarly, has a wide distribution along the coast, but its different species are limited quite distinctly by the variations in the temperature of the ocean. Other Pacific Coast forms which show marked delimitations due to the temperature conditions are the Atlantic form, *Scutella parma* (Lamarck), which is confined entirely to the boreal waters from Puget Sound to Kamchatka, and *Mellita longifissa,* which is a distinctly warm water type and now found only in the Gulf of California and the Panama region. The deeper water fauna is not reliable for temperature determinations, *Schizaster* and *Spatangus,* the more common fossil forms, occurring in both temperate and tropical zones of the world.

From the fact that the pre-Miocene echinoid faunas are largely of the spatangoid type it is impossible to gain an idea as to the temperature conditions through their distribution without taking into consideration the mulluscan life also, though the presence of *Rhynchopygus* suggests a subtropical condition. An exception to this is *Scutaster andersoni* Pack, the presence of which indicates that warm water prevailed during the Oligocene. For the Lower Miocene the echinoid fauna indicates rather warm water as the scutellas, such as *S. norrisi* (Pack), were large and highly specialized forms. Later in the Miocene the genus *Astrodapsis* appeared and rapidly became abundant. Although no species of this genus has survived to the present day,

nevertheless this type resembles some of the more tropical forms, such as *Clypeaster;* and from this similarity it may be inferred that warm temperate waters were present during the rapid development of this genus. A temperate climate, though probably somewhat cooler, continued into the Pliocene, at which time the genus *Dendraster* and subgenus *Calaster* reached their maximum development. In this connection it may also be of interest to note that *Calaster interlineatus* and *C. oregonensis* never have been found south of Monterey Bay, though they live northward along the coast of Oregon, indicating that these forms were restricted to cooler water than such species as *Dendraster gibbsii* (Rémond) and *D. ashleyi* (Arnold), which do not occur north of Monterey and are never found associated with the former species. During the upper Pliocene and Pleistocene *D. excentricus* (Eschscholtz) and *Strongylocentrotus* afford no definite information as to climatic conditions other than that it was approximately the same as the present. An exception to this is the occurrence of *Mellita longifissa* Michelin at Newport Beach, near Los Angeles, in beds of late San Pedro age. The presence of this subtropical form is direct evidence that a warm water condition existed at this time as far north as San Pedro.

From the above facts it is evident that no very definite conclusions can be reached concerning the geographic distribution of echinoids by temperature control through comparison with the Recent forms, except in a few cases. Still, if considered with other groups of life, the echinoids may be of considerable importance in this connection as a link in the chain of evidence bearing on the problem of the climatic history of the Cretaceous and Tertiary epochs of the Pacific Coast.

PHYLOGENETIC SERIES

PRINCIPAL CRITERIA USED IN CONSTRUCTION OF PHYLOGENETIC SERIES

Some of the more important criteria to be considered in the discussion of the evolution of the Pacific Coast echini are: (1) the eccentricity of the apical system; (2) the position of the periproct; (3) the size and shape of the test at maturity; (4) the amount of elevation of the abactinal portions of the ambulacra and the depression in the interambulacra; and (5) the degree of ramification of the ambulacral

furrows. The first is to be considered more especially in dealing with the genus *Dendraster.* In the general evolution of the echinoderms as a whole, the central apical system is more primitive than the eccentric one, the latter occurring only in the Exocycloida. However, some of the later forms show a less eccentric apical system than the earlier types, tending to revert to a less specialized form. The supramarginal position of the periproct in the exocyclic echinoids is a primitive character, since they have been derived from the Centrechinoidea, a regular type, in which the periproct is on the abactinal surface. However, the study of the Pacific Coast Scutellidae seems to indicate that the supramarginal position is also a retrogressive character in forms of a later evolutionary stage. This is shown in the evolution of the west coast scutellas, in which the later species, such as *S. gabbi* (Rémond), acquire the supramarginal periproct. This fact is also substantiated by the same feature in the subgenus *Calaster,* which occurs in a comparatively late horizon where the more advanced characters should be present. The size and shape of the test can be regarded as a function of the environment. Since the Clypeastroids are forms which live on the sandy bottom of the littoral zone, the roughness of the water at any particular place may result in a thicker test to withstand the wave action. A highly elevated abactinal surface may be produced so that the petaliform portion of the test, in which the tentacles are specialized as breathing organs, may be raised above the level of the sand which buries the remainder of the shell. The size of the test depends to a great extent on the food supply and temperature conditions, colder water apparently dwarfing the individuals, as in *Dendraster* (*Calaster*) *oregonensis* (Clark). It is mainly in the species of *Astrodapsis* that the raised petals and interambulacral depressions are present, and these are comparable to an advanced degree of specialization such as occurs in many other groups of animals before their extinction. The geologic succession also bears out this, for in the early forms, such as *Astrodapsis brewerianus* (Rémond), these characters are just making their appearance and finally culminate, during the later horizons, in the *Astrodapsis arnoldi* type. The ramification of the ambulacral furrows becomes more complex in the later forms, especially in those of the genus *Dendraster.* An increase in depth of the furrows is also a character which has been taken on during the later development of the Scutellidae.

STATEMENT OF THE PHYLOGENY OF THE PACIFIC COAST ECHINOID FAMILIES

The Tertiary strata of California on account of their great thickness and abundant fauna offer a remarkable sequence of fossil echinoids. The Clypeastrina is the only Cenozoic order which is represented by a sufficient number of species to permit of the working out of an evolutionary series, the other orders, Cidaroidea, Centrechinoidea, and Spatangina, though present, being only sparsely represented, and their occurrence is so scattered throughout the strata that a continuous succession is not obtained. From the clypeastroid material it has been possible to work out not only the phylogeny of the family Scutellidae itself (see fig. 2), but also that of three of its genera, namely, *Scutella, Astrodapsis,* and *Dendraster.*

The Scutellidae first appeared in the Tejon formation of the Upper Eocene and the genus *Scutella* was its first representative. At first the rise of this order was slow, and not until the Upper Miocene and Lower Pliocene was its maximum development reached. From this time on it declined until at the present time only one indigenous species, *Scutella mirabilis* (Agassiz), is living in the Pacific Ocean, where it is confined to the Japanese and Siberian coasts and the Bering Sea. During the history of the Scutellidae on the west coast three genera, *Scutella, Astrodapsis,* and *Dendraster,* have played an important part. Besides these is *Scutaster,* a highly specialized form, characterized by three lunules in the ambulacra of the trivium. It had a very short existence in the upper part of the Oligocene, where it is represented by a single species, *Scutaster andersoni* Pack. Whether a form in such an advanced stage of development originated in a relatively short time, as indicated by the existence of only one species, or whether it had its earlier stages during the Eocene, is not known, due to the fragmentary nature of the scutellid material in the Eocene and Oligocene of California.

While the genus *Scutella* was at its maximum development in the Lower and Middle Miocene the genus *Astrodapsis* was beginning to make its appearance. In the evolution of this genus the species *Astrodapsis brewerianus* (Rémond) and *A. brewerianus* var. *diabloensis* Kew are intermediate forms with characters pertaining to both genera. Although in general these forms appear to be transitional in character, nevertheless they possess some true astrodapsid features which distinctly separate them from the scutellas. A brief review of the dis-

tinguishing characters show that *A. brewerianus* has the wide open petals, and more fundamentally a different type of ambulacral plates. In *Scutella* the plates widen markedly from the ends of the petals to the ambitus, whereas in *Astrodapsis* these plates start to broaden about one-half the distance from the apical system to the margin, which gives the abactinal portions of the ambulacra a more regular appearance. Furthermore, the petals in *Astrodapsis* usually extend

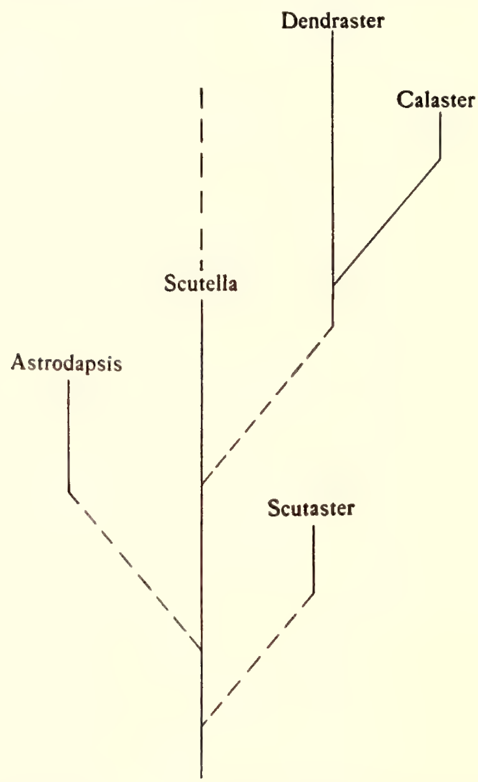

Fig. 2. Phylogenetic tree for the more important Pacific Coast genera.

nearer to the ambitus than they do in *Scutella*. That it has been originally derived from *Scutella* is shown by its internal structure, which is clearly of the scutellid type; the flush petals also point to the same derivation for it. Since *A. brewerianus* possesses all of these astrodapsid characters it suggests that, although this is a rather primitive form of this group, it is comparatively well advanced in its stage of evolution beyond the original scutellid type. This can be accounted for by the assumption that it had undergone an intervening development between the scutellid type and the astrodapsid type in some

other region, or, on the other hand, that the earlier forms are not preserved to us.

SCUTELLA SERIES

So far as known at the present time, the evolution of the genus *Scutella* on the Pacific Coast begins with the Upper Eocene form *Scutella coosensis* Kew, which occurs in Oregon. In California only fragmentary remains of Eocene scutellas have been found, and the same is true with the Oligocene, the only known forms on the coast being from Washington. Though scutellas probably existed during the Oligocene in the vicinity of California, up to the present time no traces of them occur. From the scanty evidence afforded by two species found in comparatively distant areas very little can be judged as to the evolution of the Scutellidae prior to the Miocene.

The *Scutella* group as a whole is more or less disunited; in only a few cases can any series of species be traced through a continuous section of strata, and there is no evidence of gradational evolutionary changes. In all, about thirteen species are represented, which are scattered throughout the formations over a large part of the Pacific Coast.

In the phylogenetic series as represented by the chart (see fig. 3), two main series are shown: that of the *Scutella blancoensis* Kew, *S. merriami* (Anderson), and *S. gabbi* (Rémond) as forming one main line of descent, and *S. coosensis* Kew and *S. fairbanksi* Arnold the other. The *S. merriami* occurring in the Lower Miocene is closely allied to the *S. gabbi* found in the Upper Miocene. Both forms are comparatively simple, the later type differing only in minor characters, such as a slightly different position of the anus and in its general shape.

The first series is represented by forms of small size which show differences in marginal outline and thickness, position of the periproct, and degree of elevation of the abactinal surface. As in the other groups, no continuous series is represented except possibly that containing *S. merriami, S. andersoni* Twitchell, and *S. tejonensis* Kew, of which the last two are the more highly specialized. Since *S. merriami* possesses a marginal periproct, the supramarginal position in the later species has been considered a retrogressive character in this series. *S. andersoni* has more highly developed characters, such as pronounced marginal notching and a supramarginal periproct. *S. tejonensis,* in addition, has wide, open, flaring petals which extend

to the margin, somewhat resembling those found in the genus *Astrodapsis.* The *Scutella gabbi* group in the Upper Miocene has given rise to several forms, and *S. gabbi* itself may be considered as a direct descendant of *S. merriami,* though differing only slightly. It shows a somewhat more advanced stage in that the periproct tends to assume a supramarginal position. *Scutella gabbi* var. *tenuis* Kew probably

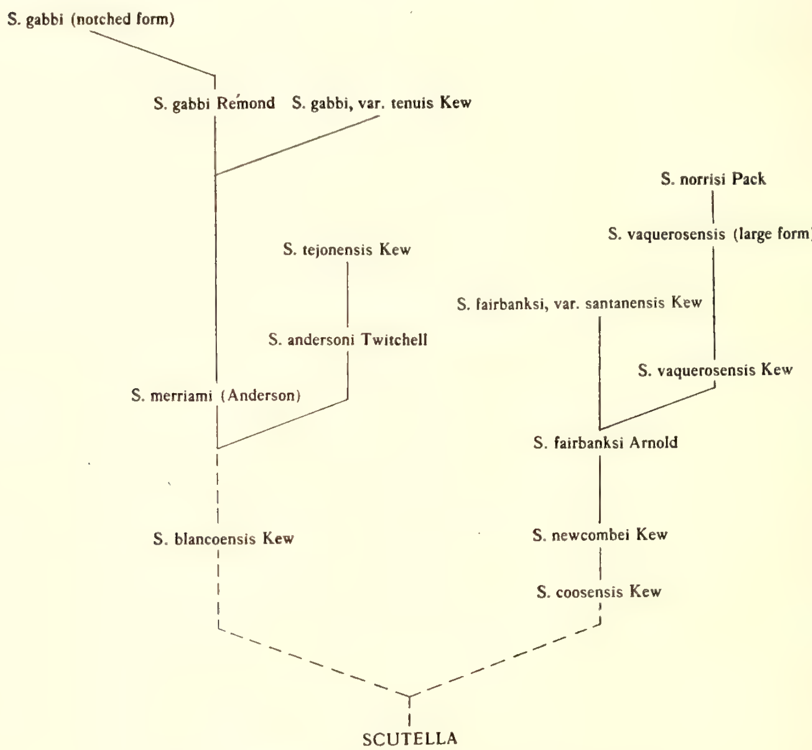

Fig. 3. Phylogenetic tree for the Genus *Scutella.*

is somewhat more specialized than *S. gabbi* in that it is a larger form and relatively much thinner. The other form of *S. gabbi* (notched form) is later in time, but is hardly thought to represent even a varietal difference inasmuch as it differs only in having a slight notching of the margin in the posterior ambulacral areas. *S. blancoensis* Kew is a species similar to *S. gabbi,* though it lived in an entirely separate geographic province, viz., in the vicinity of Cape Blanco, Oregon, during the Oligocene. It is somewhat less highly developed than *S. gabbi,* the periproct being entirely supramarginal and the test thinner. The supramarginal position of the periproct in this

species is evidently a primitive character and indicates an earlier type of *Scutella* on the Pacific Coast.

A number of species which seem more closely related to the pre-Miocene forms, *Scutella coosensis* Kew and *S. newcombei* Kew, than to the *S. merriami* type are found in the Lower Miocene. One of the best known is *S. fairbanksi* Arnold, occurring in a number of localities in southern California. In general appearance, on account of their large size and thin tests, the Lower Miocene forms resemble the earlier Eocene and Oligocene species more than they do the more intimately associated *S. merriami* type. The supramarginal position of the periproct, one of the most characteristic features of *S. fairbanksi*, may be a more specialized character, but in all the other forms of the Lower Miocene it is marginal. The *S. fairbanksi* var. *santanensis* Kew, found in the Santa Ana Mountains, seems to be somewhat more highly developed in having marginal notches in the posterior ambulacra. This form leads to the more deeply notched *S. vaquerosensis* Kew, and later to the very irregularly shaped *S. norrisi* Pack through the large gradational form of *S. vaquerosensis*. All of these forms are not found in the same region nor in continuous stratigraphic series; probably they are closely connected, and represent different stages of development. *S. fairbanksi* has been reported from the Sespe, lying below the Vaqueros, the formation in which all these species are found. This suggests that *S. fairbanksi* is the earliest form of this group in California. In the section in which *S. vaquerosensis* occurs the smaller variety is near the base of the series of strata, whereas the larger one is at the top. The exact stratigraphic occurrence of *S. norrisi* in the Vaqueros formation is somewhat doubtful. In the discussion of the geographic ranges it is pointed out that this species has a comparatively wide distribution; this indicates that it is a type having a high degree of specialization, which is of greater importance than if it were a form with a limited distribution arising from especially favorable conditions of segregation and environment.

ASTRODAPSIS SERIES

This genus, which is typically developed in the Miocene and Pliocene strata of California, has given to us an almost complete history of its evolution. Its continuous stages are revealed by the great number of specimens which have been obtained that show the development of the genus from an early, simple, scutellid-like form to one

that is probably more highly specialized than any other Pacific Coast species known. During its generic history (see fig. 4) several subsidiary groups have branched off from the main *Astrodapsis tumidus* group. In the order of appearance, these subdivisions of the genus are the groups characterized by *A. antiselli* Conrad, *A. whitneyi* Rémond, *A. arnoldi* (Pack), and *A. fernandoensis* Pack. Each forms a distinct group possessing common characters, their development, for the most part, taking place in certain separate geographic provinces. These groups are not separate subgenera, for the reason that each is bound closely to the main genus *Astrodapsis* by more important characteristics than those which distinguish the groups themselves. The major characters which tie these groups together are: (1) the elevated petaliferous portions of the ambulacra separated by grooved interambulacra; (2) the central or subcentral apical system, possessing four genital pores; (3) simple ambulacral furrows; (4) an inframarginal or marginal, but never supramarginal, periproct; (5) the extension of the petals to, or very near, the margin; and (6) the broadening of the ambulacral plates a considerable distance inward from the end of the petal. The group characters will be given in their separate discussions.

The development of astrodapsid characters is rapid, for within the same strata where the true *Astrodapsis brewerianus* (Rémond) occurs, a variety of this species is found possessing slightly raised petals, which is one of the characters of the true *Astrodapsis.* The next major astrodapsid feature acquired, is the depressed interambulacral areas. An incipient stage of this character is noticeable in *A. brewerianus.* This species also shows more or less elevated petals in every specimen. Up to this time the development has been along one main line, but subsequent to this period the evolution of this genus becomes more varied, and offshoots from the central stock commence. The first of these is *A. antiselli* Conrad which, though closely resembling *A. cierboensis* Kew, is in a stage of development that has taken place at a later time in a different region, the Salinas Valley area. *A. antiselli* subsequently gave rise to the two forms *A. margaritanus* Kew and *A. ornatus* Kew, the three species being the first of the group to form one of the main branches in the evolutionary tree of the genus *Astrodapsis.* The latter two species correspond in degree of evolution to *A. tumidus* Rémond of the San Pablo Bay-Mount Diablo province. *A margaritanus, A. ornatus,* and *A. tumidus*

possess well developed astrodapsid features, having distinctly elevated petals, grooved interambulacral areas, and simple but marked ambulacral furrows.

The development of the main group, that of *Astrodapsis tumidus,*

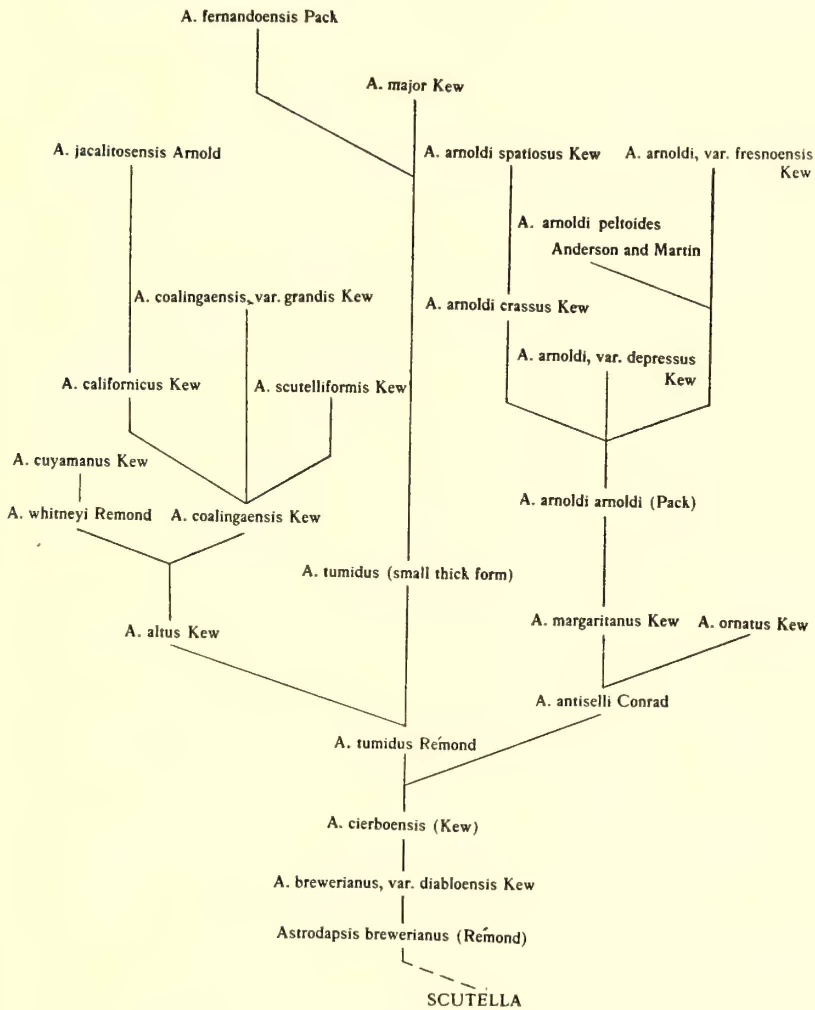

Fig. 4. Phylogenetic tree for the Genus *Astrodapsis.*

gives rise later on to a variety which has been designated as *A. tumidus* (*small thick form*). This variety also occurs in the Upper San Pablo (Santa Margarita) formation of the Salinas Valley district, which shows it to be fairly widespread. Immediately after this form of *A. tumidus* became extinct, three new groups made their appearance:

(1) that characterized by *A. major* (Kew), which is the direct descendant of the *A. tumidus* stock; (2) that characterized by *A. arnoldi* (Pack), a descendant of *A. antiselli;* and (3) that by *A. fernandoensis* Pack. Each of the three groups are marked by highly developed astrodapsid features, such as very tumid petals and deep interambulacral grooves. The presence of a new feature, the auxiliary grooves along the sides of the petals, is noteworthy as a more advanced character. *A. major* was confined to the San Pablo Bay-Mount Diablo area, but in the southern San Joaquin Valley area the same stage of evolution is represented by *A. arnoldi peltoides* (Anderson and Martin). In the Salinas Valley province the second group was developing at this time which had the same general characters, though differing in minor details, e.g., the petals are not so highly elevated and usually narrower, and the test is usually less tumid. *A. arnoldi arnoldi* gave rise to a variety, *A. arnoldi* var. *depressus.* Contemporaneous with *A. arnoldi arnoldi* several other subspecies were present in different parts of this province. These were *A. arnoldi* var. *fresnoensis* Kew and *A. arnoldi crassus* Kew, which probably developed later into *A. arnoldi spatiosus* Kew. The third group which was derived from the *A. tumidus* stalk was *A. fernandoensis* Pack. This group is characterized by the presence of remarkably large tubercles, together with the typical astrodapsid features. So far, only one species of this group has geen recognized, occurring in Elsemere Canyon, near Newhall, Los Angeles County.

In the interval of time between the deposition of the beds containing *Astrodapsis brewerianus* and those yielding *A. tumidus* (*small thick form*), a group comparable to the groups had its start, viz., the *Astrodapsis whitneyi* Rémond group. The *A. whitneyi* group has the raised petals, simple ambulacral furrows, and the inframarginal position of the anus, which are true astrodapsid characters, yet the *A. whitneyi* forms differ in having smooth interambulacral areas, a much thinner margin, and a flattened submarginal area, giving the test a bell-shaped appearance. An intermediate form is probably *A. altus* Kew, which has smooth interambulacral areas and a high, conical test, the flat submarginal area not yet having been acquired. This group not only developed in the San Pablo Bay-Mount Diablo area but also in other parts of the state where the Upper San Pablo (Santa Margarita) formation is present, with *A. whitneyi* as the one species common to all localities; the other species originating from the same stalk were characteristic of definite geographic areas.

Simultaneously with the development of *A. whitneyi* in the north and in the Salinas Valley area there was a form comparable to it which had a much more complex evolution in the southern San Joaquin Valley area. This group is characterized by the species *A. coalingaensis* Kew, which, though closely resembling *A. whitneyi,* differs in being ornamented with larger tubercles, a feature also possessed by the other members. The species arising from *A. coalingaensis* are *A. scutelliformis* Kew, *A. coalingaensis* var. *grandis* Kew, and *A. californicus* Kew. From *A. californicus* was probably developed *A. jacalitosensis* Arnold, a species living somewhat later in Lower Etchegoin (Jacalitos) time. The ungrooved interambulacral areas and more or less bell-shaped appearance of the last species ally it with this group. In the Cuyama River district of Santa Barbara County a species quite close to *A. whitneyi,* but possessing wider petals, is present. This form, *A. cuyamanus* Kew, probably represents contemporaneous evolution in a different geographical province.

In summarizing the data on this genus, there is found to be a main stalk descended from the genus *Scutella* by transitional forms, which gradually evolve into more complex species until the most highly developed *Astrodapsis* is reached, after which the genus suddenly becomes extinct. From this main line of descent at least four groups have branched off, the most important being the *A. whitneyi* and *A. arnoldi* groups. Each of these four groups gave rise to evolutionary series, and probably represent development along similar lines in separate geographic provinces.

DENDRASTER SERIES

This genus was evidently derived from the scutellas, but through what transitional forms it is at present not known. The first *Dendraster* to appear was *D. gibbsii* (Rémond), which is found earliest in the strata of the Lower Etchegoin (Jacalitos) formation of the Pliocene. The sudden appearance of a form with a markedly eccentric apical system, a well advanced character, may be explained on the assumption that it may have been an immigrant from another region where its earlier evolutionary stages took place. The series (see fig. 5) may be divided into two main groups, that characterized by *D. gibbsi* and that by *D. excentricus* (Eschscholtz). Only one small subsidiary group is thrown off, that distinguished by *D. coalingaensis* Twitchell. *Calaster,* the subgenus of *Dendraster,* has an entirely separate evolution;

although derived from the scutellas, the time at which the division took place is uncertain.

Dendraster gibbsii has a comparatively long range, extending from the Lower Etchegoin (Jacalitos) well toward the top of the Upper Etchegoin. During this time it varies only slightly in the size of the individual, probably due to difference in environment. In the Pecten coalingensis zone of the Upper Etchegoin the echinoids of the *D. gibbsii* type seem to become slightly retrogressive in character. This is exemplified by *D. hesperis* Kew, which has a less eccentric apical system than the earlier type, but, on the other hand, has become somewhat thicker. The change in the eccentricity of the apical system here seems to parallel the same sequence which occurs in the large group in which *D. excentricus* is the last member.

Among the first of the dendrasters is *D. jacalitosensis* Kew, which is characterized by a relatively thin test, slightly eccentric apical system, petals with broad interporiferous and narrow poriferous areas, and marginal notches in the posterior ambulacra. It occurs in the Lower Etchegoin (Jacalitos) formation in the lowest beds in which fossils are found. The apical system, which is less eccentric than in *D. gibbsii,* together with its stratigraphic occurrence, suggests that it may be a more primitive form than the latter and more closely related to the scutellas. The character of the petals do not necessarily indicate this since in the California scutellas the poriferous areas are comparatively broad.

The *D. coalingaensis* group is represented by three species, the other two being *D. arnoldi* Twitchell and *D. perrini* (Weaver). These forms are very similar, the differences which distinguish them being mainly in the thickness of the test and the arrangement of petals. They are probably derived from the earlier dendrasters, and show a distinct evolutionary series from *D. coalingaensis* to *D. perrini,* which is somewhat more highly developed than the others.

Toward the top of the Etchegoin formation, a different type of dendraster appears, which is characterized by the thinness of the test. The earliest form possessing this character is *D. gibbsii* var. *humilis* Kew, which gives rise to *D. ashleyi* (Arnold), a form which represents the most highly specialized species in the development of this genus; it is characterized by an extremely eccentric apical system and a broad odd anterior petal. This species was fairly widespread, being present both in the Coalinga district and in the Santa Maria oil district of Santa Barbara County. Near the latter district, in the

Pliocene of the Santa Ynez River region, a variety with a slightly less eccentric apical system but retaining the wide anterior petal is met with. This variety is of larger size and the less eccentric apical system indicates that it is a forerunner of the Upper Pliocene dendrasters, in which the apical system becomes still less eccentric.

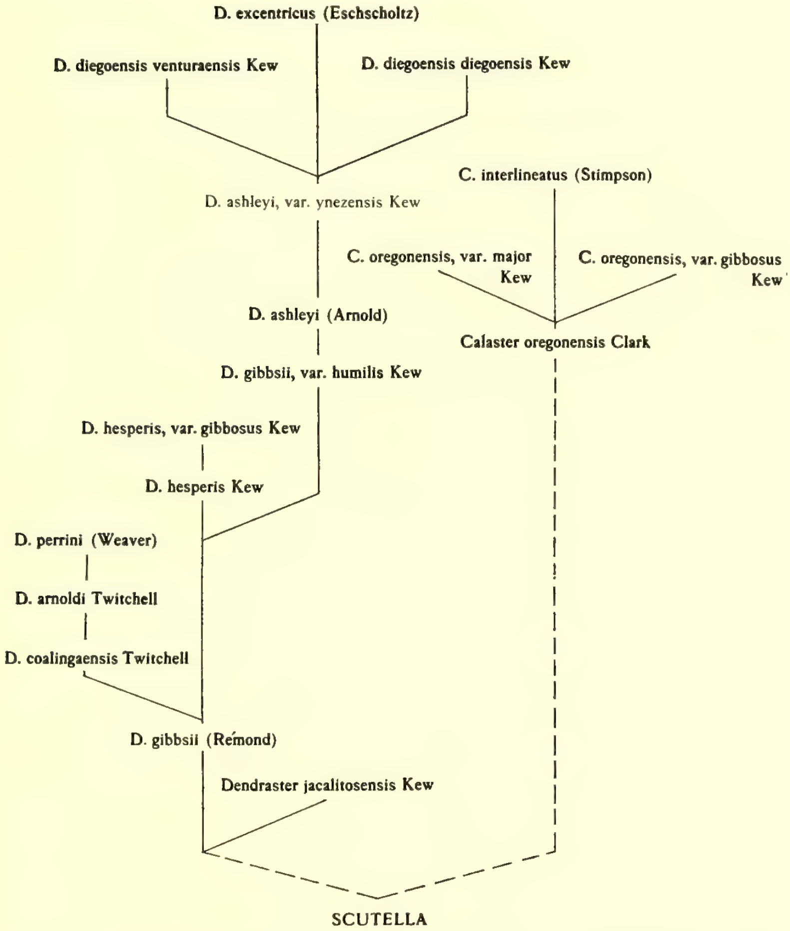

Fig. 5. Phylogenetic tree for the Genus *Dendraster* and Subgenus *Calaster.*

During the Upper Pliocene two distinct forms were present in the deposits of southern California, while farther to the north, echinoderms indistinguishable from *D. excentricus* (Eschscholtz) of the Recent epoch lived. In the San Diego formation the *D. diegoensis diegoensis* Kew shows some differences from the former, which are probably due to environment or perhaps a slightly higher degree of specialization.

It has a somewhat larger and heavier test, which may have been acquired by inhabiting a region more exposed to the waves. The narrow angle between the petals of the bivium, one of its specific differences, cannot be accounted for at present through any evolutionary change. At the same time that *D. diegoensis diegoensis* was living in the vicinity of San Diego a subspecies, *D. diegoensis venturaensis* Kew, was present in the region of Ventura County. This form closely resembles the former yet differs in being somewhat more specialized in having a markedly elevated abactinal surface within the radius of the petals. Another difference is in the slightly raised petals, a character which was found to be an indication of advancement in the dendraster series.

The Recent *Dendraster excentricus* shows a slightly different arrangement in the angulation of the petals from that in *D. diegoensis,* but the main progressive character is probably the more extended poriferous areas of the petals.

The subgenus *Dendraster* (*Calaster*) is short-lived and includes but three forms, which inhabited only the cool waters of the Pacific Coast. It was probably derived directly from the scutellas, as *D.* (*Calaster*) *oregonensis* (Clark) shows relationship to them in having only a slightly eccentric apical system and in that the distinguishing subgeneric character, the supramarginal periproct, appears to be a further advancement of a similar feature which is found in the later scutellid forms, such as *S. gabbii* (Rémond). Although *D.* (*Calaster*) *oregonensis,* together with *D.* (*Calaster*) *oregonensis* var. *gibbosus* Kew and *D.* (*Calaster*) *oregonensis* var. *major* Kew, is stratigraphically lower than the other species, *D.* (*Calaster*) *interlineatus,* the latter seems to be somewhat retrogressive in having a less eccentric apical system. As has been noticed in tracing out the history of the other dendrasters, the later forms seem to have less eccentric apical systems, so this group may be similar in this respect. The much greater size of the test probably indicates a more favorable environment.

Summarizing the development of the genus *Dendraster* and the subgenus *Calaster,* their history begins with relatively well advanced forms which appear to be introduced suddenly as immigrant species, then after reaching a high stage of specialization they decline somewhat, until finally only one species is left, *D. excentricus,* which is probably a retrogressive form.

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CLASS **ECHINOIDEA** Bronn

ORDER CIDAROIDA Duncan

FAMILY CIDARIDAE Gray

Genus CIDARIS Leske

CIDARIS LORENZANUS (Arnold)

Plate 3, figure 4

Cidaris branneri Arnold. Proc. U. S. Nat. Mus., vol. 29, 1903, pp. 363, 364, pl. 33, fig. 5.

Cidaris branneri. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 698.

Cidaris branneri. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 158, pl. 73, fig. 5.

Holotype.—No. 1056, U. S. Nat. Mus.

Arnold's description will be given, since no specimen of this species has been examined:

Test unknown. Spines, long, slender, circular in cross section, attaining a length of at least 25 millimeters and a diameter of over 2 millimeters. Surface of spine smooth for about one-fifth its length from the base; above this it is ornamented by ten longitudinal rows of elongated nodes or granules which are barely connected near the smooth portion, but which partake more and more of the character of nodose ribs toward the distal end; the last one-fifth of the spine is ornamented by five prominent, slightly nodose ribs; the extreme end is blunt and rounded; collar at base only faintly developed.

The spines of this species are easily distinguishable from those of *C. merriami,* new species, from the Eocene, by their smaller size, fewer but much more prominently nodose longitudinal ribs, and smooth basal portion. No complete spine of *C. merriami* was obtained, so that the smooth basal section may possibly be a characteristic of this latter species as well as *C. lorenzanus.*

According to Twitchell, the dimensions are:

Length 20 millimeters; diameter, basal end 2.2 millimeters, distal end 1.1 millimeters.

The name *Cidaris branneri* has been previously used by White[1] for a species occurring in Brazil. This has necessitated the change to *C. lorenzanus* (Arnold).

Geologic horizon.—San Lorenzo formation, Oligocene.

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[1] White C. A., Contributions to the paleontology of Brazil, Museo nac. Rio de Janeiro Archivos, vol. 7, pp. 247–248, pl. 28, figs. 2, 3, 1888.

GEOLOGIC DISTRIBUTION OF THE CRETACEOUS AND CENOZOIC ECHINOIDEA OF THE PACIFIC COAST

	Cretaceous		Eocene			Oligocene			Miocene				Pliocene										Pleistocene	
	Knoxville	Chico	Martinez	Meganos	Tejon	Sooke beds	Agasoma gravidum zone	San Lorenzo	Vaqueros	Briones	Lower San Pablo group	Upper San Pablo group (Santa Margarita)	Lower Etchegoin (Jacalitos)	Upper Etchegoin	Lower Fernando	Upper Fernando	Merced	Purisima	Empire	Wildcat	Carrizo Creek	San Diego	San Pedro	Recent
Echinoidea																								
Cidaroida																								
Cidaridae																								
Cidaris lorenzanus (Arnold)								×																
Cidaris martinezensis Kew			×																					
Cidaris merriami Arnold																								
Cidaris tehamaensis Clark	×																							
Cidaris thouarsii(?) Valenciennes									×															
Cidaris, sp. a Dickerson			×																					
Cidaris, sp. indet.																								
Centrechinoida																								
Camarodonta																								
Echinidae																								
Tripneustes (Hipponoë) californicus (Kew)																					×			
Strongylocentrotidae																								
Strongylocentrotus franciscanus A. Agassiz																								
Strongylocentrotus purpuratus (Stimpson)																								
Exocycloida																								
Clypeastrina																								
Clypeastridae																								
Clypeaster bowersi Weaver																								
Clypeaster carrizoensis Kew																								
Clypeaster deserti Kew																								
Fibularidae																								
Sismondia (?) arnoldi Twitchell																								
Sismondia (?) coalingaensis Twitchell																								
Scutellidae																								
Scutella andersoni Twitchell					×				×															
Scutella blancoensis Kew																								
Scutella coosensis Kew																								
Scutella fairbanksi Arnold																								
Scutella fairbanksi var. santanensis Kew																								
Scutella gabbi (Rémond)											×													
Scutella gabbi var. tenuis Kew											×													
Scutella merriami (Anderson)																								
Scutella newcombei Kew						×																		
Scutella norrisi Pack									×															
Scutella tejonensis Kew									×															
Scutella vaquerosensis Kew																								
Astrodapsis altus Kew												×												
Astrodapsis antisellii Conrad												×												
Astrodapsis arnoldi arnoldi (Pack)										×			×	×		×	×	×						
Astrodapsis arnoldi var. depressus Kew													×											
Astrodapsis arnoldi crassus Kew													×											
Astrodapsis arnoldi fresnoensis Kew													×											
Astrodapsis arnoldi peltoides (Anderson and Martin)													×									×		
Astrodapsis arnoldi spatiosus Kew													×											
Astrodapsis brewerianus (Rémond)										×														
Astrodapsis brewerianus var. diabloensis Kew										×														
Astrodapsis californicus Kew												×								×	×	×		
Astrodapsis cierboensis (Kew)											×													
Astrodapsis coalingaensis Kew												×												
Astrodapsis coalingaensis var. grandis Kew																								
Astrodapsis cuyamanus Kew												×												
Astrodapsis fernandoensis Pack															×									
Astrodapsis jacalitosensis Arnold													×											
Astrodapsis major (Kew)							×				×	×												
Astrodapsis margaritanus Kew												×										×		
Astrodapsis ornatus Kew												×									×	×		
Astrodapsis (?) pabloensis (Kew)											×						×							
Astrodapsis scutelliformis Kew												×												
Astrodapsis tumidus Rémond												×												
Astrodapsis whitneyi Rémond								×				×									×			
Dendraster arnoldi Twitchell													×	×								×		×
Dendraster ashleyi (Arnold)													×	?	×							×		
Dendraster asheyi var. ynezensis Kew															×									
Dendraster coalingaensis Twitchell														×					×	×		×	×	
Dendraster diegoensis diegoensis Kew															×	×						×		
Dendraster diegoensis venturaensis Kew																×						×		
Dendraster excentricus (Eschscholtz)															×								×	×
Dendraster gibbsii (Rémond)													×	×				?						
Dendraster gibbsii var. humilis Kew														×	?		×					×	×	
Dendraster hesperis Kew														×										
Dendraster hesperis var. gibbosus Kew														×										
Dendraster jacalitosensis Kew													×			×								
Dendraster pacificus Kew																	×					×	×	
Dendraster perrini (Weaver)														×						×				
Dendraster (Calaster) interlineatus (Stimpson)					×			×									×		×	×				
Dendraster (Calaster) oregonensis (Clark)					×													?	×	×			×	
Dendraster (Calaster) oregonensis var. gibbosus Kew			×				×													×				
Dendraster (Calaster) oregonensis var. major Kew							×									×	×							
Scutaster andersoni Pack						×	×			×		×		×						×		×		
Encope tenuis Kew																					×			
Mellita longifissa Michelin			×			×						×	×	×									×	
Spatangina																								
Cassiduloidea																								
Cassidulidae																								
Cassidulus (Rhynchopygus) californicus (Anderson)					×									×				×			×			
Cassidulus (Rhynchopygus) ellipticus Kew									×															
Cassidulus (Rhynchopygus) mexicanus Kew												×[b]		×	×	×	×						×	
Cassidulus (Rhynchopygus) ynezensis Kew									×															
Catopygus californicus Kew		×															×						×	×
Catopygus cajonensis Kew			×			×							×					×						
Spatangoidea																								
Spatangidae																								
Hemiaster cholamensis Kew		×	×			×		×														×	×	
Hemiaster californicus Clark		×			×							×									×		×	
Hemiaster alamedensis Kew		×			×							×						×				×	×	×
Epiaster depressus Kew		×	×		×	×		×												×		×	×	
Hemiaster oregonensis Kew		×	×																×	×			×	×
Schizaster californicus (Weaver)							×					×			×									
Schizaster cordiformis Kew			×					×							×							×	×	
Schizaster diabloensis Kew			×	×		×	×	×									×			×	×		×	×
Schizaster lecontei Merriam			×			×	×	×			×	×								×	×	×	×	×
Schizaster martinezensis Kew			×															×		×	×	×	×	×
Schizaster stalderi Weaver													×							×			×	×
Spatangus pachecoensis Pack			×		×																		×	

a Monterey shale.

b Occurs in strata equivalent to Gatun formation of Gulf Coastal Plain.

Locality.—Holotype from Santa Cruz quadrangle, Santa Cruz County, locality 109, on Bear Creek, four miles above its confluence with the San Lorenzo River, California.

CIDARIS MARTINEZENSIS Kew, n. sp.

Plate 3, figures 2*a*, 2*b*, 2*c*

Cidaris (?) sp. *c*. Dickerson, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, 1914, p. 121, pl. 6.

Figured specimen.—No. 11400 Univ. Calif. Coll. Invert. Pal.

Test of small size. Measurements of specimen no. 11400: greatest diameter 11.8 mm., greatest height 5.2 mm. Upper surface somewhat flattened, lower surface concave to the peristome. Peristome very large. Ambulacra rather broad. Interambulacra bearing two rows of large primary tubercles whose areolas closely approach each other; outer areas marked by a ring of granules. The casts of spines of this species are long, measuring at least 10 mm. in length.

Geologic horizon.—Martinez group, Lower Eocene.

Locality.—Swett's ranch, Contra Costa County, California.

CIDARIS MERRIAMI Arnold

Plate 3, figure 3

Cidaris merriami Arnold. Proc. U. S. Nat. Mus., vol. 34, 1908, p. 359, pl. 32, fig. 8.

Cidaris merriami. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 696.

Cidaris merriami. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 114–115, pl. 55, fig. 4.

Cidaris sp. (*d*) Dickerson. Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, 1914, p. 121, pl. 6, figs. 6*a*–6*b*.

Holotype.—No. 165438 U. S. Nat Mus.

Inasmuch as no further characters were obtainable from the specimen at hand, Arnold's original description will be given:

The test of this species is unknown, but the abundance and well-marked characteristics of the fragments of the spines has been deemed of enough importance to justify a specific name. Seven specimens have been obtained at the type locality, each showing the characters described above.

Spines subcircular in cross section, as much as 4 millimeters in diameter and probably over 40 millimeters in length, tapering very slightly; surface sculptured by 13 or 14 prominent, narrow, nodose, ridge-like, longitudinal ribs separated by narrow, deeply incised grooves; the nodes are well defined, especially in the younger stages of growth, and are subelliptical in cross section, their longer axis being parallel with the axis of the spine.

H. L. Clark, who examined the specimens for Arnold, says:

All appear to belong to one species, except possibly one fragment. That piece might *possibly* have come from quite a different species. I am very glad to see this material of *merriami,* for it satisfies me that the species must have been allied to, if not identical with, *Tetrocidaris perplexa* Clark (Cidaridae, p. 205, pl. 6, figs. 1, 2; pl. 7, figs. 1–4, 1907), the only other living littoral cidarid known from north of Panama (other, I mean, than *thouarsii*). So your material shows that the ancestors of both *thouarsii* and *perplexa* lived in the Tertiary in California.

Geologic horizon.—Martinez group, Lower Eocene.

Localities.—Holotype from Santa Cruz quadrangle, San Mateo County, locality 25; ridge between head-waters of San Lorenzo River and Pescadero Creek, California. Specimen, no. 11401 Univ. Calif. Coll. Invert. Pal., from north side of Mount Diablo, Contra Costa County, California.

CIDARIS TEHAMAENSIS Clark

Plate 3, figure 1

Cidaris tehamaensis Clark. U. S. Geol. Surv. Mon., vol. 54, 1915, p. 44, pl. 9, fig. 1.

Holotype.—No. 31195 U. S. Nat. Mus.

The writer has had no opportunity to study a specimen of this species, and for this reason the description of Clark will be given verbatim:

This species is represented by a well-preserved spine that is large and club-shaped. The granules are large and disposed in rows extending from the neck to the point of the spine.

Geologic horizon.—Knoxville formation, Lower Cretaceous.

Locality.—Shelton's ranch, Tehama County, California.

CIDARIS THOUARSII (?) Valenciennes

Cidaris thouarsii Valenciennes. Agassiz and Desor, Catalogue raisonné des échinodermes, Ann. des sci. nat., vol. 6, 1846, p. 326.

Cidaris sp. *a* Arnold. Proc. U. S. Nat. Mus., vol. 34, 1908, pp. 351, 359.

Cidaris sp. *a.* Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 701.

Cidaris thouarsii (?). Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 179.

Specimen in U. S. Nat. Mus. Coll.

Inasmuch as no material has been available for study the description used by Twitchell is given:

This species, which Arnold has referred to under the name *Cidaris* sp. *a,* is regarded by H. L. Clark as probably *C. thouarsii.* He says in a letter quoted by Arnold: The wax cast (*Cidaris* sp. *a*) is a spine of a true cidaris and very much like many spines of some individuals of the species of Cidaris common on the west coast of Lower California, Mexico and Central America, *C. thouarsii.* I do not think it shows a single feature by which it can be distinguished from *thouarsii;* it is certainly from the ancestor of that species.

Geologic horizon.—Monterey shale, Middle Miocene.

Locality.—Santa Cruz quadrangle, California.

CIDARIS sp. *a* Dickerson

Cidaris sp. *a* Dickerson. Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, 1914, p. 121, pl. 6, figs. 4*a*, 4*b*.

Cotypes.—Nos. 11729 and 11853 Univ. Calif. Coll. Invert. Pal.

Dickerson's description is as follows:

Test unknown. Spines long, very slender, circular in cross section. Certain incomplete specimens are 15 mm. long and only 1 mm. in diameter with only a slight taper. Surface of spine marked by microscopic longitudinal lines or ribs. The distal end is marked by a small ball which is decorated by about fourteen strong rounded ribs. This ball terminates in a rounded tip. The base is marked by a well-developed collar and a rounded socket in its end. The base does not appear to be ornamented.

The surface of the rock is covered with spines which have been weathered out. The description is based upon several fragments of spines.

Geologic horizon.—Martinez group, Lower Eocene.

Localities.—Mount Diablo region, Univ. Calif. locs. 245 and 1556.

CIDARIS indet. sp.

Cidaris sp. Kew, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, 1914, p. 51.

Genital plates pentagonal, with rounded sides. Genital pores large. Abactinal surface has a single row of primary tubercles at both margins of the interambulacral area. Interporiferous area contains a double row of primaries. Below the ambitus tubercles sporadically placed. Ambulacral area about one-third that of the interambulacral area. Ambulacral pores arranged in straight radial rows. Spines cylindrical, elongate, and granulated, the granulation being arranged in vertical rows. Internal structure of the spines consists of rows of mesh-like cells radiating from a central point.

Specimen.—No. 12361 Univ. Calif. Coll. Invert. Pal.

The description of the test is taken from an imperfect young specimen.

Geologic horizon.—Lower Division of Carrizo Creek beds, Pliocene.

Locality.—Coyote Mountain, Imperial County, California, Univ. Calif. loc. 738.

Order CENTRECHINOIDA Jackson
Suborder CAMARODONTA Jackson
Family ECHINIDAE Agassiz
Genus TRIPNEUSTES Agassiz

TRIPNEUSTES (HIPPONOË) CALIFORNICUS (Kew)

Plate 3, figure 5

Hipponoë californica Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1914, pp. 50–51, pl. 1, fig. 2.

Hipponoë californica. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 111.

Holotype.—No. 10055 Univ. Calif. Coll. Invert. Pal.

Size of test large. Measurements of specimen no. 10055: transverse diameter approximately 85 mm., greatest thickness approximately 75 mm. Thin and conical in shape, with the ambitus situated near the base. Actinal surface somewhat concave. Ambulacra broad, with the poriferous area equal to the non-poriferous area. Poriferous zones consisting of three pairs of conjugate pores arranged obliquely and placed one above the other, forming radial lines. Middle pair sporadic. Furrows joining pores become very marked below ambitus. Tubercles on ambulacra irregularly placed on both poriferous and non-poriferous plates. Interambulacral area twice as wide as the ambulacral area. Five primary tubercles on each interambulacral plate near the ambitus and arranged in radial rows. The number of tubercles becomes less toward the apical system.

Related forms.—The Recent *Hipponoë depressa* A. Agassiz found in the Gulf of California and on the west coast of Lower California is closely allied to *Tripneustes californicus.* The latter has fewer tubercles than the former; also the ambitus is situated lower down, giving it a more distinctly conical shape.

Geologic horizon.—Lower Division of the Carrizo Creek beds, Pliocene.

Locality.—Coyote Mountain, Imperial County, California, Univ. Calif. loc. 2064.

Family STRONGYLOCENTROTIDAE Gregory

Genus STRONGYLOCENTROTUS Brandt

STRONGYLOCENTROTUS FRANCISCANUS A. Agassiz

Plate 4, figures 1*a*, 1*b*, 1*c*

Toxocidaris franciscana A. Agassiz. Bull. Mus. Comp. Zool., vol. 1, 1863, p. 22.

Toxocidaris globosa A. Agassiz. Proc. Acad. Nat. Sci. Phila., vol. 15, 1863, p. 356.

Strongylocentrotus franciscanus A. Agassiz. Rev. Ech., Ill. Cat. Mus. Comp. Zool., pt. 1, 1872, p. 163; pt. 3, 1872, p. 442, pl. 5*b*, figs. 1–2, pl. 7, figs. 10, 10*a*.

Strongylocentrotus franciscanus. Arnold, Calif. Acad. Sci. Mem., vol. 3, 1903, p. 90.

Strongylocentrotus franciscanus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 706.

Strongylocentrotus franciscanus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 223.

Figured specimen.—No. 11389 Univ. Calif. Coll. Invert. Pal.

This specimen is of rather small size. Measurements: greatest diameter 38.7 mm., greatest thickness 16 mm. Two main vertical rows of large tubercles in the interambulacral areas which occupy the greater part of the plate; two short rows of smaller tubercles near the median line, and a row along the border of this area; other smaller secondaries are present. Ambulacral areas contain two rows of primaries, smaller in size than those of the interambulacral areas; a median row between the primaries and a row of secondaries in each poriferous area are present. Arcs of pores oblique and contain as many as nine pairs. Both upper and lower surfaces considerably flattened.

Arnold, in discussing its occurrence on the Pacific Coast, says:

> This is the large sea urchin of the west coast. Spines which are probably of this species have been found in the lower San Pedro series of Deadman Island. The spines of this species are distinguishable by their large size and longitudinal striations. Some of the spines are 20 millimeters long and 3 millimeters in diameter.

Geologic horizon.—Upper Fernando formation, Upper Pliocene; associated with *Dendraster diegoensis* subsp. *venturaensis* Kew. San Pedro formation (lower part), Pleistocene; Recent.

Localities.—Las Posas Hills, Ventura County, California, figured specimen; San Pedro, Los Angeles County, California; Fourth and Hill streets, Los Angeles, California (Moody).

STRONGYLOCENTROTUS PURPURATUS (Stimpson)

Echinus purpuratus Stimpson. Crust. Echin. Pac. Coast, 1857, p. 86.
Strongylocentrotus purpuratus. A. Agassiz, Rev. Ech., Ill. Cat. Mus. Comp. Zool., pt. 1, 1872, p. 165; pt. 3, p. 449, pl. 5*a*, figs. 5–6, p. 16, fig. 7, pl. 36, fig. 9.
Strongylocentrotus purpuratus. Arnold, Calif. Acad. Sci. Mem., vol. 3, 1903, pp. 90, 91.
Strongylocentrotus purpuratus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 707.
Strongylocentrotus purpuratus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 223.

The occurrence of spines of this form is rather common in the Upper Pliocene and the Pleistocene formations of the west coast. Arnold discusses their occurrence as follows:

Numerous spines of this small purple sea urchin have been found in the San Pedro series. No part of the test has ever been discovered in these deposits, to the writer's knowledge. Several nearly perfect tests of this species were found in the Pleistocene (lower San Pedro series) deposits at the bath house, Santa Barbara. A nearly perfect test was also found in the upper horizon of the San Diego formation (Pleistocene (?) at Pacific Beach, near San Diego.

Geologic horizon.—Upper Fernando, San Diego, and San Pedro formations, Upper Pliocene, Pleistocene, and Recent.

Localities.—Pacific Beach, San Diego County; Fourth and Hill streets, Los Angeles (Moody); San Pedro and Santa Barbara, California (Arnold).

Order EXOCYCLOIDA Jackson
Suborder CLYPEASTRINA Gregory

Family CLYPEASTRIDAE Agassiz
Genus CLYPEASTER Lamarck

CLYPEASTER BOWERSI Weaver

Plate 5, figures 1*a*, 1*b*; plate 6, figure 1

Clypeaster bowersi Weaver. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1908, pp. 271–272, pl. 21, fig. 1, pl. 22, fig. 1.
Clypeaster bowersi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 701.
Clypeaster bowersi. Kew, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1914, pp. 50–51, pl. 3, figs. 1*a*–1*b*, and pl. 4, fig. 1.
Clypeaster bowersi. Clark and Twitchell, U. S. Geol. Survey Mon., vol. 54, 1915, p. 209, pl. 96, figs. 1*a*-*b*.

Cotypes.—Nos. 10059 and 10060 Univ. Calif. Coll. Invert. Pal.

Outline suboval to pentagonal. Test thick and very large. Measurements of average sized specimen, no. 10060 Univ. Calif. Coll. Invert. Pal.: anteroposterior diameter 133 mm., transverse diameter 113.7 mm., greatest thickness 41 mm. Profile rounded to subtriangular. Edges of test swollen in some specimens. Margin slightly reëntrant opposite the interambulacral areas. Petals broad, obovate, and nearly closed at their extremities. Poriferous areas narrow and slightly sunken. Interporiferous areas of petals somewhat raised. Two lateral petals of the trivium shorter than the other petals. Odd anterior petal narrower than the others. Pores conjugate. Apical system central and small. Actinal surface nearly flat, with peristome deeply sunken. Anus large, depressed, and located immediately below the margin of the test. Ambulacral furrows narrow, deep, and extending from the mouth to the edge of the test. Tubercles small, crowded, and uniform in size over the whole test.

Related forms.—*Clypeaster bowersi* Weaver resembles very closely *Echinanthus* (*Clypeaster?*) *testudinarius* Gray living in the Gulf of California. The average size of *Clypeaster bowersi* is larger and it has a slightly more elevated test than *Echinanthus testudinarius.* The anus of the former is situated at the edge of the test while that of the latter is situated away from the margin a distance equal to its own diameter.

Geologic horizon.—Lower Division of the Carrizo Creek beds, Pliocene.

Locality.—Coyote Mountain, Imperial County, California, Univ. Calif. loc. 2064.

CLYPEASTER CARRIZOENSIS Kew

Plate 7, figures *2a*, *2b*

Clypeaster carrizoensis Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8. 1914, p. 49, pl. 2, figs. *2a–2b*.

Holotype.—No. 10047 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements: maximum anteroposterior diameter 24 mm., maximum transverse diameter 21 mm., maximum height 7 mm. Outline pentagonal to suboval, with slight notch opposite the interambulacral areas. Test depressed, thick, and edge slightly swollen. Apical system central, elevated but little. Petals tumid and wide open at the ends, extending over one-half the distance to the margin. Interporiferous spaces slightly raised, but pores sunken, especially the

outer row, the inner row being situated on the slope of the raised area of the petal. Pores conjugate. Actinal surface deeply sunken to the peristome. Ambulacral furrows broad, deep, and extending undivided to the edge of the test. Anus inframarginal. Tubercles small and of uniform size on both actinal and abactinal surfaces.

Related forms.—This species is not related to any living form in the Gulf of California. It resembles slightly *Scutella gabbi* (Rémond) from the San Pablo formation of middle California. The shape of *Clypeaster carrizoensis* is more nearly pentagonal, the edges of the test thicker, and the apical system more nearly central than in *Scutella gabbi.*

Geologic horizon.—Lower Division of the Carrizo Creek beds, Pliocene.

Locality.—Coyote Mountain, Imperial County, California. Holotype from Univ. Calif. loc. 738.

CLYPEASTER DESERTI Kew

Plate 7, figures 1*a*, 1*b*

Clypeaster deserti Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, p. 48, pl. 3.

Holotype.—No. 10056 Univ. Calif. Coll. Invert. Pal.

Test large. Average measurements: anteroposterior diameter 80.3 mm., transverse diameter 78 mm., greatest thickness 10.6 mm. Pentagonal to subcircular in outline. Margins broadly notched opposite the interambulacral areas, the two lateral posterior notches being larger and the median posterior notch smaller than the anterior ones. Test not markedly thick, but margin swollen except opposite the posterior interambulacral area. Apical system central and raised. Petals short, very tumid, reaching about half the distance to the edge of the test and tending to close at their ends, those of the trivium to a greater degree than those of the bivium. Anterior petal longer than the other four, which are of approximately the same length. Poriferous areas broad, and pores conjugate. Tubercles small and of the same size on both sides. Actinal surface flat, with mouth central and slightly sunken. Anus large and inframarginal. Internal structure made up of concentric rows of slender pillars near the edge of the test.

Related forms.—This species may be distinguished from the Recent *Clypeaster rotundus* A. Agassiz of the Gulf of California, by its more

nearly pentagonal shape and thinner margin. In *C. deserti* the odd anterior petal is the longest, and slightly open, the remainder being of the same length. The longest petals in *C. rotundus* are the bivium, and these are nearly closed.

Geologic horizon.—Lower Division of the Carrizo Creek beds, Pliocene.

Localities.—Coyote Mountain and Carrizo Valley, Imperial County, California. Type from Univ. Calif. loc. 2064.

FAMILY FIBULARIIDAE Gray

Genus SISMONDIA Desor

SISMONDIA (?) ARNOLDI Twitchell

Plate 4, figures 2*a*, 2*b*

Astrodapsis sp. indet. Arnold. U. S. Geol. Surv. Bull. no. 396, 1909, p. 30, pl. 28, figs. 5–5*a*.

Astrodapsis sp. indet. Arnold and Anderson, U. S. Geol. Surv. Bull. no. 398, 1910, p. 128, pl. 50, fig. 5.

Astrodapsis sp. indet. Stefanini. Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Sismondia (?) arnoldi Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 182–183, pl. 85, figs. 1*a*–1*b*,

Holotype.—No. 165538 U. S. Nat. Mus.

Since no specimens of this species have been available for study Twitchell's description is given here verbatim:

This little echinoid, one of the smallest occurring in the Tertiary deposits of the Pacific Coast, was first figured but not described by Ralph Arnold, of the U. S. Geological Survey, in whose honor the species is named. The test is very small, being less than half an inch in diameter. In marginal outline it is suboval, with a slight tendency toward the subpentagonal, the anterior end being slightly angulated, the posterior broader and rounded. The whole form is much depressed, slightly convex above, slightly concave below; margin of moderate thickness. Apex central. The ambulacral petals are long, reaching the margin; poriferous zones narrow, diverging in straight lines from apex to margin; pores of both rows round. The whole test is covered with small but rather conspicuous tubercles. The apical system is central, with a conspicuous tumid madreporite. The other details could not be made out on the specimen. The peristome is relatively large, central, subcircular to subpentagonal. The ambulacral grooves appear as rather well defined, simple, straight lines for a short distance out from the peristome, beyond which they become obscure. The periproct is very small, circular, inframarginal, almost marginal.

Dimensions.—Length 10.5 millimeters; width 9.5 millimeters.

Related forms.—*S. arnoldi* resembles *S.* (?) *coalingaensis* and *Scutella* (?) *merriami,* but differs from both in having petals extending to the margin, with straight, diverging poriferous zones.

Geologic horizon.—Etchegoin formation, Pliocene.

Locality.—Four miles southeast of northwest end of Kettleman Hills, Coalinga district, California.

SISMONDIA (?) COALINGAENSIS Twitchell

Plate 4, figures 3*a*, 3*b*

Sismondia (?) *coalingaensis* Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, p. 183, pl. 85, figs. 2*a*–2*c*.

Holotype.—No. 165717 U. S. Nat. Mus.

Since no specimens of this species have been available for study Twitchell's description is given here verbatim:

The test of this species is very small, rarely exceeding one-half an inch in length. In marginal outline it is suboval to subovate, broader posteriorly than anteriorly. The whole form much depressed, slightly tumid centrally; margin rather thin. Apex subcentral or slightly eccentric posteriorly. Lower surface concave.

The ambulacral petals are subelliptical in outline, extending a little more than half way to the margin; the posterior pair shorter than the anterior pair; pores round, pairs of pores conjugated. The whole test is covered with small but conspicuous tubercles, scattered irregularly.

The apical system is subcentral or slightly eccentric posteriorly, coincident with the apex. The details could not be made out on the specimen studied.

The peristome and ambulacral grooves could not be made out. The periproct is small, inframarginal, almost marginal.

Dimensions.—Length 12 millimeters; width 10 millimeters; height 2 millimeters.

Related forms.—*S. coalingaensis* resembles *Sismondia* (?) *arnoldi* and *Scutella* (?) *merriami*. From the former it differs in having shorter, subelliptical petals and from the latter in lacking the tumid petals and in having a more longitudinally oval marginal outline.

Geologic horizon.—Etchegoin formation, Pliocene.

Locality.—Jacalitos Creek, half a mile east of Kreyenhagen's, Coalinga district, California.

Family SCUTELLIDAE Agassiz

Genus SCUTELLA Lamarck

SCUTELLA ANDERSONI Twitchell

Plate 12, figures 1*a*, 1*b*, 1*c*

Scutella sp. *a* F. M. Anderson. Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 2, 1905, p. 193, pl. 13, fig. 8.

Scutella andersoni Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 183–184, pl. 85, figs. 3*a*–3*d*.

Holotype.—No. 165719 U. S. Nat. Mus.; *figured specimens* nos. 11363 and 11364 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of specimen no. 11363: antero-posterior diameter 25.4 mm., transverse diameter 25.4 mm., greatest height

5.0 mm. Outline varies from subcircular to suboval or subovate; ambitus broadly and deeply notched in the two posterior ambulacral areas, so that a lobe-like appearance is given to the posterior portion of the test; very slightly notched in the anterior ambulacral areas; greatest lateral diameter posterior to the center of the test. Upper surface much more depressed in the posterior than in the anterior part; rises from a very thin edge to a low pointed apex which is situated slightly anterior to the center of the test; profile from margin to summit is usually somewhat concave. Apical system eccentric to the anterior, and in most specimens coincides with the apex of the test, though it may be posterior to the latter. Madreporic area large and subpentagonal in outline; four large genital pores present. Five small perforated radial plates are situated at the base of the petals. Ambulacra considerably wider than the interambulacra at the ambitus. Petals of moderate size and extending about two-thirds the distance from the the apical system to the margin; petals of the bivium slightly longer than the others, with the odd anterior one the shortest; rows of pores regularly curved, giving them a sublanceolate appearance; pores converge but little in the distal ends of the petals; odd anterior petal wide open and broader than the others. Poriferous areas relatively broad, being about two-thirds the width of the interporiferous area. Outer rows of pores slit-like in outline; inner rows smaller and suboval. Poriferous areas somewhat sunken below the general level of the test. Anterior median portion of the abactinal surface longitudinally and broadly ridged, the elevation extending back into the odd posterior interambulacral area; interporiferous areas of the lateral petals slightly elevated. Inferior surface very slightly concave. Peristome anteriorly eccentric, relatively large, and subcircular in outline. Ambulacral furrows are broad, indistinct grooves extending to the edge of the test. Periproct large, round, and supramarginal, though in some specimens it is nearly marginal. Tubercles small, numerous, and of the same size on both surfaces.

Related forms.—From *Scutella merriami* (F. M. Anderson) this form differs in that the periproct is supramarginal or marginal instead of being inframarginal; that it has a much thinner test, and lacks the swollen margin; that the notching of the ambitus in the ambulacral areas is greater; and that the poriferous areas are relatively narrower. These forms are closely related and may be confused due to their similarity in size and in that the raised odd anterior petal is common to both. From *S. tejonensis* Kew it may be readily distinguished by

lacking the flaring petals, which extend close to the margin. From *S. gabbi* (Rémond) it is separated by its more depressed test and deep posterior ambulacral notches in the margin. It differs further from *S. blancoensis* Kew in that the periproct is not so strongly supramarginal.

Geologic horizon.—Vaqueros formation, Lower Miocene; Tejon, Upper Eocene formation (Twitchell) (?). Associated with *S. tejonensis* Kew.

Localities.—Holotype from Devil's Den District, Kern County, California (Twitchell). Figured specimens from basal beds of the Vaqueros formation in the Tejon Hills, Kern County, California, Univ. Cal. loc. 3358; near base of the Vaqueros along the road at the foot of the Casitas grade, Ventura County, California; west of Coalinga, Kern County, California (F. M. Anderson).

SCUTELLA BLANCOENSIS Kew, n. sp.

Plate 11, figures 1*a*, 1*b*, 1*c*

Cotypes.—Nos. 11358, 11359, Univ. Calif. Coll. Pal.

Test small. Measurements of specimen 11358: anteroposterior diameter 22.3 mm., transverse diameter 23.8 mm., greatest height 4.0 mm. Outline subovate, pointed behind. Apical system relatively large and eccentric anteriorly; four genital pores present. Upper surface considerably depressed, especially in the posterior area; rises to the apex, which is situated anterior to the apical system and comparatively close to the margin; anterior part of the upper surface of the test considerably more elevated than the posterior part, and with the margin thickened. Lateral petals elliptical in outline, rather long, narrow, and extending about three-fourths the distance to the margin. Inner rows of pores converging but little at their ends; outer rows converging close to the inner rows at the extremity of the petals with a few sporadic pores beyond the petals, the rows diverging widely. Poriferous areas comparatively wide, each being almost as wide as the interporiferous area. Odd anterior petal wide, broadly open at its extremity, and shorter than the paired petals; poriferous areas about as wide as those of the lateral petals, but the interporiferous area is nearly twice the width; inner rows of pores diverge to the end; outer rows diverge strongly until about one-half the distance to the end, whence they continue in parallel lines, gradually coming

closer to the inner row, and, as the distal portion is approached, both rows strongly diverge. Outer rows of pores slightly sunken in all petals. Inferior surface flat, with very faint, straight, undivided ambulacral lines in indistinct broad grooves, which do not reach the margin. Peristome subpentagonal in outline and slightly anteriorly eccentric. Periproct round, supramarginal, and placed about its own diameter from the edge of the test. Tubercles on the superior surface very small and crowded; those of the inferior surface larger and placed in well defined scrobicules.

Related forms.—This species closely resembles *Scutella gabbi* (Rémond), but it may be separated from the latter by the position of the periproct, which is situated farther from the edge of the test than in *S. gabbi,* in which it is nearly marginal; the test is less elevated and slopes posteriorly to a thinner margin; the marginal outline is more subovate; and the petals are narrower and more strongly elliptical in outline. The anteroposterior profile of the test resembles *S. andersoni* Twitchell, but *S. blancoensis* may be distinguished by its lack of distinct posterior marginal notches, and from the fact that the periproct is supramarginal and not marginal. From *Scutella merriami* (Anderson) it differs in being less tumid, in having a subovate marginal outline, and in the strongly supramarginal position of the periproct.

Geologic horizon.—San Lorenzo series, Oligocene.

Localities.—Basal sandstone, sea cliffs north of lighthouse, Cape Blanco, Oregon, Leland Stanford Jr. Univ. Dept. Geol. loc., N. P. 26, and Calif. Acad. Sci. loc. no. 17.

SCUTELLA COOSENSIS Kew, n. sp.

Plate 8, figures 1*a*, 1*b*

Holotype.—No. 446 Calif. Acad. Sci. Coll. Pal.

Test of medium size, and greatly depressed. Measurements of holotype: anteroposterior diameter 52 mm., transverse diameter approximately 80 mm., greatest height approximately 8 mm. Marginal outline transversely suboval. Margin thin, with the upper surface gently and regularly arched to the summit, the latter being situated slightly anterior to the center of the test. Apical system central; madreporic area large, four genital pores present opposite the four lateral corners. Ambulacra extremely wide at the ambitus, the odd anterior one being four times the width of the adjoining interambulacra, the other am-

bulacra about three times the width of the adjoining areas. Petals of moderate size, symmetrical, and reaching slightly over one-half the distance from the apical system to the margin; odd anterior and posterior lateral petals of equal length and somewhat shorter than the anterior lateral pair; all of same width, with very wide poriferous areas and narrow interporiferous areas, except that of the odd posterior petal, which is slightly wider than the others. Inner rows of oval pores extend in nearly parallel lines to the end of the petal, converging but little at their ends; outer rows of slit-like pores diverge at first to a much greater degree and then continue approximately parallel to the inner rows until near the extremity of the petal, when they sharply converge close to the inner rows; outer rows of pores in the odd anterior petal curve more regularly from the base to the end. Lower surface nearly flat. Periproct very small and marginal.

Related forms.—This form most closely resembles the Vaqueros, Lower Miocene species, *Scutella vaquerosensis* Kew, but may easily be distinguished by the shape of the petals, which in *S. coosensis* are narrower, with wider poriferous areas in proportion to the interporiferous areas; also the odd anterior petal of *S. vaquerosensis* is broader and wide open at its extremity. *S. fairbanksi* Arnold differs in having a supramarginal periproct, a subcircular outline, and in that the petals possess broader interambulacral areas.

Geologic horizon.—Eocene series (Meganos?).

Locality.—Holotype from north side of Sec. 4, T. 26 S., R. 14 W., west of Yokam Point, Coos County, Oregon (Calif. Acad. Sci. Coll.).

SCUTELLA FAIRBANKSI Arnold

Plate 11, figures 2*a*, 2*b*, 2*c*

Scutella fairbanksi (Merriam MS.) Arnold. Proc. U. S. Nat. Mus., vol. 32, 1907, p. 542, pl. 46, fig. 3; pl. 43, figs. 5, 5*a*.

Scutella fairbanksi. Eldridge and Arnold, U. S. Geol. Surv. Bull., no. 309, 1907, pl. 29, fig. 9.

Scutella fairbanksi. Pack, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 276–277, pl. 23, fig. 1.

Echinarachnius fairbanksi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Scutella fairbanksi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 184–185, pl. 85, figs. 4–6.

Holotype.—No. 11017; *figured specimen,* no. 11360. Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen 11017: antero-posterior diameter approximately 49 mm., transverse diameter 53.7 mm., greatest height 5.2 mm. Outline subcircular to transversely sub-oval, usually with broad, indistinct marginal notches in the ambulacral areas; test greatly depressed, with margin markedly thin. Apical system anteriorly eccentric. Upper surface arched to a low summit, which is forward of the apical system and relatively close to the anterior margin. Apical star comparatively small; madreporite large and pentagonal in shape; four genital pores present, the odd posterior one being absent. Ambulacra broader than the interambulacra at the ambitus. Ambulacral areas widen rapidly from the ends of the petals to the margin, but the interambulacral areas maintain a uniform size from that point to the edge of the test. Abactinal portion of the ambulacra petaloid. Lateral petals narrow and subelliptical in outline; both rows of pores converge slightly toward the distal end of the petals, the convergence of the outer rows being greater than that of the inner rows. Poriferous areas wide, and nearly as broad as the interporiferous area. Odd anterior petal distinctly different from the others; much broader, with a greater width of the interporiferous area and slightly elevated; inner rows of pores diverge somewhat near the distal end of the petal, and the outer rows converge but slightly if at all. A few pairs of pores in divergent rows continue for a short distance beyond the ends of all the petals. Pores in all petals oval in shape and conjugated. Very small scrobicular tubercles are crowded over both surfaces, but become larger and less numerous near the peristome. Inferior surface flat, with deep ambulacral furrows which extend in wavy lines from the peristome to the margin; they have a slight tendency to branch near the edge of the test. Peristome round, small, and slightly eccentric anteriorly. Periproct round, small, supramarginal, and situated about its own diameter from the edge of the test.

Related forms.—*Scutella fairbanksi* differs from *S. gabbi* (Rémond), to which it is closely allied, in that it attains a much greater size and has slight marginal notches in the ambulacral areas; in having deeper ambulacral furrows on the inferior surface; in that the periproct is entirely supramarginal, the test relatively thinner, and the submarginal area of the upper surface comparatively broader. With the exception of the difference that the margin is notched, these distinguishing characters separate it from the *large form* and *notched form* of *S. gabbi*. *S. gabbi* var. *tenuis* Kew differs in being of smaller

average size; in that the rows converge more closely toward the distal end of the petals, and in that the slope of the upper surface is more or less concave, whereas that of *S. fairbanksi* is markedly convex; moreover, the ambulacral furrows are not so prominent on the actinal surface. It may easily be distinguished from *Dendraster* (*Calaster*) *interlineatus* (Stimpson) and *D.* (*Calaster*) *oregonensis* (W. B. Clark) by its slightly anterior eccentric apical system.

Geologic horizon.—Vaqueros formation, Lower Miocene. Associated with the fauna of the Turritella ineziana zone. Reported from the middle part of the Sespe formation, Oligocene(?).

Localities.—Holotype from "near Torrey Canyon Wells, southwest of Piru, Ventura County" (Arnold); also occurs "in tributary entering Little Sespe Creek at the Foot-of-the-Hill Wells, Ventura County" (Arnold); Sespe Canyon, Ventura County, California (Pack, Arnold); south side of Tar Creek Canyon, Ventura County, California, Univ. Calif. loc. 2728 (Louderback). South side of Santa Clara Valley, Shiells Canyon, NW. 1/4 of Sec. 10, T. 10 S., R. 19 W., Ventura County, California.

SCUTELLA FAIRBANSKI SANTANENSIS Kew, n. var.

Plate 11, figures *3a, 3b, 3c*

Cotypes.—Nos. 11361 and 11362 Univ. Calif. Coll. Invert. Pal.

This form differs from the typical *Scutella fairbanksi* Arnold in its thinner test; the profile of the upper surface from the ambitus to the summit is usually slightly concave or straight in contrast to that of the *S. fairbanksi,* which is convex; the margin is more strongly notched in the ambulacral areas, giving the test a broadly subovate outline in some specimens; and the summit coincides more closely with the apical system.

Related forms.—This variety is most closely allied to *Scutella gabbi* var. *tenuis* Kew than is the typical form, but differs in having a greater marginal notching in the ambulacral areas; in attaining a larger size; and in that the rows of pores do not converge so much in the distal ends of the petals.

Geologic horizon.—Vaqueros formation, Lower Miocene. Associated with the fauna of the Turritella ineziana zone.

Localities.—Holotype from Santa Ana Mountains, Orange County, California, Univ. Calif. loc. 2339.

SCUTELLA GABBI (Rémond)

Plate 12, figures 4*a*, 4*b*; plate 13, figures 1, 2*a*, 2*b*, 3

Clypeaster gabbi Rémond. Proc. Calif. Acad. Sci., vol. 3, 1863, pp. 53–54.
Clypeaster gabbi. Meek, Smithson. Misc. Coll., vol. 7, no. 183, 1864, p. 2.
Clypeaster gabbi. Gabb, Geol. Surv. Calif. Pal., vol. 2, 1869, pp. 36, 109, pl. 12, figs. 64, 64*a*.
Clypeaster gabbi. Cooper, Cat. Calif. Fossils, Seventh Ann. Rept. Calif. State Mineralogist, 1888, p. 27.
Scutella (*Clypeaster*) *gabbi.* Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, 1898, pp. 110, 111, 113, 114, 117.
Scutella gabbi. Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, 1899, p. 168, pl. 22, figs. 5, 5*a*.
Echinarachnius gabbi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.
Scutella gabbi. Kew, Univ. Calif. Publ. Bull. Dept. Geol., vol. 18, 1915, pp. 366–368, pl. 39, figs. 1–3.
Scutella gabbi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 189, pl. 88, figs. 1*a*, 1*b*.
Clypeaster ? gabbi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 211.

Neotype.—No. 11001 Univ. Calif. Coll. Invert. Pal.

Test small. Average measurements: anteroposterior diameter 25.3 mm., transverse diameter 26.3 mm., greatest height 6.3 mm. Outline circular to subcircular, subpentagonal in some specimens; transverse diameter often greater than the anteroposterior diameter; very faintly notched at the ambitus in the posterior ambulacral areas. Upper surface depressed, with margin rather thin but having a tendency to be thicker in young forms. Summit usually anterior to the apical system, which is slightly eccentric anteriorly. Four large genital pores present, the one opposite the posterior interambulacral area being absent; five small radial plates, each possessing a pore. Petals usually unequal in length; those of the trivium extend nearer to the margin than those of the bivium; posterior lateral pair longest, the anterior laterals shortest, with the odd petal usually intermediate or about as long as the posterior pair. Petals open at their ends; odd anterior one wide open. Inner rows of pores of lateral pairs of petals in almost straight lines, converging very slightly toward the end; outer rows converge to a greater degree, which in most specimens almost close with the inner rows at the distal end of the petal. Pairs of small pores continue to the margin, the pairs diverging from each other to a marked degree. Each poriferous area of about the same width as the interporiferous area, except in the odd anterior petal, where they are about one-half the width. Ambulacra widen rapidly from the ends of the petals to

the margin, where they are nearly twice the width of the interambulacra; the latter are widest opposite the ends of the petals and become narrower at the margin. Inferior surface flat to very slightly concave. Peristome small, and approximately central. Periproct marginal to entirely supramarginal, small, and round. Ambulacral lines weak and seldom seen; they divide a short distance from the peristome and continue nearly to the margin.

Variations.—A *large form* is found near the base of the San Pablo group which differs from the typical *Scutella gabbi* in being of larger size and having a relatively more depressed test. In the Upper San Pablo group a *notched form* occurs, which differs in having a somewhat deeper notching at the ambitus in the ambulacral areas. It is slightly thinner, and the petals on some of the specimens have a tendency to be slightly raised.

Related forms.—*Scutella gabbi* is most closely related to *S. merriami* (F. M. Anderson); but differs in that it has a more elevated test; does not possess the swollen margin; lacks the greater tumidity of the anterior odd ambulacral area; and in that the periproct may be more or less supramarginal in *S. gabbi* whereas in *S. merriami* it is always marginal. *S. andersoni* Twitchell is distinguished from it, according to Twitchell, "....by its longitudinally ridged upper surface, its longitudinally concave lower surface, and its pronounced marginal notches opposite the posterior paired petals." According to Pack, *S. fairbanksi* Arnold, to which it is often compared, differs considerably in "...attaining a greater size, in having a slightly undulating marginal outline, in having deeper and better marked furrows on the actinal surface, and in having the anal pore entirely upon the upper surface." Other differences show that the test is relatively thinner, and that the petals do not extend so near the margin.

Geologic horizon.—Lower San Pablo group, Upper Miocene, associated with *S. gabbi* var. *tenuis* Kew.

Localities.—Occurs ". . . abundantly on the eastern shore of San Pablo Bay, south of Mare Island in soft sandstone of Miocene age" (Rémond). Neotype from Contra Costa County, California.

Discussion.—Doubt is expressed by Twitchell as to the synonomy of the *Scutella gabbi* described and figured by Merriam with that described by Rémond, in as much as a few dissimilarities occur in the two descriptions. A great many specimens are at the writer's disposal in the collections of the University of California, which have

been collected from the type locality of the "eastern shore of San Pablo Bay south of Mare Island, California, in soft sandstones of Miocene age." The types used by Merriam were from the same locality.

Twitchell enumerates three sets of details in which the two descriptions differ. These are as follows (quoting from Twitchell): "Rémond's was subelevated, comparatively thick and with margin rounded. Merriam's is much depressed, and with margin thin. The petals of Rémond's form were elongated and open at their extremities—those of Merriam's are short and, excepting the anterior one, are nearly closed at the ends. In Rémond's form the ambulacral furrows are straight, which led to his placing the form in the genus *Clypeaster;* in Merriam's the furrows divide dichotomously a little less than half way to the margin, which indicates a Scutella." The terms used by both Rémond and Merriam are for the most part relative, and their meaning is dependent upon the manner in which the respective authors used them. For this reason the writer has concluded that the first two sets should in this case be considered as of little value in the determination of the similarity of the two forms. In the third difference, whether the ambulacral furrows divide or not, it was found, after examining a great number of specimens, that straight, shallow, indistinct furrows do exist, but that in some cases dichotomously bifurcating ambulacral lines are present. This, it is believed, is sufficient evidence for placing this species in the genus *Scutella.* Only one specimen in the large collection available was found which had bifurcating lines, though several forms showed the ambulacral furrows. This last character is probably what Rémond saw and used as the basis of his determination of the genus.

SCUTELLA GABBI var. TENUIS Kew

Plate 13, figures 4*a*, 4*b*

Scutella gabbi var. *tenuis* Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 368–369, pl. 39, fig. 4.

Holotype.—No. 11005; *figured specimen* no. 11370, Univ. Calif. Coll. Invert. Pal.

This form is characterized by its extreme thinness. It is larger than *Scutella gabbi* Rémond. Average measurements: anteroposterior diameter 33.5 mm., transverse diameter 34.5 mm., greatest thickness 5.8 mm. It is more strongly depressed; its edge is much thinner,

and the notching in the ambulacral areas is deeper. It resembles *Scutella fairbanksi* Arnold, but differs in its smaller size and in that the rows of pores of the petals converge more strongly in the distal part. The ratio between the length of the petals and the distance from the apical system to the ambitus is less in *S. fairbanksi* than in *S. gabbi* var. *tenuis,* but the ratio of the latter compared with the same ratio in *S. gabbi* shows a close resemblance.

	S. gabbi	S. gabbi var. tenuis	S. fairbanksi
Average length of odd anterior petal / Average distance from apical system to ambitus =	.6905	.674	.5945

The ratio of the length of the petals of the bivium to the distance from the apical system to the ambitus shows similar results.

It may be separated from *Scutella andersoni* Twitchell by its less strongly notched margin in the posterior ambulacral areas; by its more nearly circular outline, and its thinner test.

Geologic horizon.—Immediately above the basal beds in the San Pablo group, Upper Miocene.

Locality.—Holotype from San Pablo Bay district, Contra Costa County, California.

SCUTELLA MERRIAMI (F. M. Anderson)

Plate 12, figures *3a, 3b, 3c, 3d, 3e, 3f*

Astrodapsis merriami F. M. Anderson, Calif. Acad. Sci., ser. 3, vol. 2, 1905, pp. 193–194, pl. 14, figs. 33, 34.

Scutella merriami. Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, p. 18, pl. 6, fig. 4.

Scutella merriami. Arnold and R. Anderson, U. S. Geol. Surv. Bull., no. 398, 1910, pp. 85, 86, 87, pl. 38, fig. 4.

Scutella (?) merriami. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 185–186, pl. 85, figs. *7a, 7b, 7c, 8a, 8b.*

Sismondia merriami. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 702.

Cotypes.—Nos. 53 and 54 Calif. Acad. Sci. Coll. Pal.

Test small. Measurements of specimen no. 53: anteroposterior diameter 22.8 mm., transverse diameter 22.7 mm., greatest height 3.2 mm. Subcircular in outline, and with upper surface greatly depressed; margin swollen, and usually broadly notched in the ambulacral areas, the notching being more prominent in the two posterior areas. Apical system anteriorly eccentric; apex slightly anterior to the apical system. Lateral petals wide, partially closed, the pores

converging but little toward the extremities of the petals; odd anterior one wide open, the rows of pores not converging. Petals of the trivium reach nearly to the margin of the test, but those of the bivium only about two-thirds the distance to the margin. Odd anterior petal somewhat elevated, forming the highest portion of the test. The angle between the anterior lateral petals very wide, being almost 180°, whereas the angle between the petals of the bivium is about 60°. Pores conjugate and extend in parallel rows beyond the ends of the petals almost to the margin; each poriferous area approximately equal to the interporiferous area in the lateral petals; the interporiferous area of the odd petal is wider. Actinal surface flat. Peristome slightly sunken. Ambulacral furrows usually obliterated, but when visible are broad, straight, and undivided. In some specimens ambulacral lines are present, which tend to bifurcate. Periproct marginal. Internal structure consists of radial partitions with connecting supports near the periphery of the test.

Related forms.—This species differs from *Scutella gabbi* (Rémond) mainly in the more depressed test; more swollen margin; in the elevation of the odd anterior petal; and in the constant marginal position of the periproct. It also resembles *S. andersoni* Twitchell, but may be distinguished from this form by the lack of the posterior marginal lobe in the odd interambulacral area; in its thicker and more swollen margin; in the marginal position of the periproct, which in *S. andersoni* is supramarginal. *S. tejonensis* Kew may be easily separated by its wide open, flaring petals.

Geologic horizon.—Lower part of Monterey group, Lower Miocene (?). Occurs in beds associated with the Turritella ocoyana zone fauna.

Localities.—Cotypes in Calif. Acad. Sci. Coll. from along the east side of the Temblor Range in Kern County, California; also occurs in Tejon Hills, Kern County, California, and about one mile north of El Toro, Orange County, California.

SCUTELLA NEWCOMBEI Kew, n. sp.

Plate 8, figures 2*a*, 2*b*

Holotype.—No. 11356 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Approximate measurements of holotype: anteroposterior diameter 40 mm., transverse diameter 44 mm., greatest elevation 7.8 mm. Outline subcircular, with margin truncated in the

odd anterior ambulacral area; margin slightly thicker in the anterior part. Apical system anteriorly eccentric to a slight degree. Upper surface much depressed; rises gradually to a low apex, which is anterior to the apical system. Ambulacral area nearly twice the width of the interambulacra at the ambitus; ambulacra petaloid. Lateral petals subelliptical in outline; angle between the axes of the anterior lateral petals is nearly 180°. Inner rows of pores diverge gradually for about two-thirds the length of the petal and then converge slightly to the end. Outer rows diverge somewhat more at first and converge to a greater degree in the distal end. This arrangement of pores gives the petals an appearance of having a slight tendency to be closed at their extremities. Each poriferous area about one-half the width of the interporiferous area. Odd anterior petal wider than the others, due to the greater width of the interporiferous area; inner rows of pores in this petal diverge to the end; outer rows converge slightly in the distal part. This arrangement gives the petal a wide open, or flaring appearance. All petals extend about two-thirds the distance to the margin. Inferior surface flat, with ambulacral furrows extending from the peristome to the margin, and in the specimen examined appear to be simple and undivided. Peristome central, rather large, and round. Periproct small, inframarginal, and situated about midway from the posterior margin to the mouth. Tubercles on the upper surface small and crowded; those on the inferior surface somewhat larger, and placed in distinct scrobicules.

Related forms.—This form seems to be closely related to *Scutella blancoensis* Kew, but differs in that it is considerably larger and does not possess the angular posterior margin; the petals do not extend so near to the margin; the angle between the two anterior lateral petals is greater, the axes of the two forming an approximately straight line; the anterior margin in the odd ambulacral area is truncated; and the poriferous areas of the petals are somewhat narrower. It also resembles *S. gabbi* (Rémond), *large form,* but may easily be distinguished by its larger size, and the truncation of the margin in the anterior ambulacral area. In this latter character it is like *S. fairbanksi* Arnold, but differs from this species in having wider and much longer petals which are flush with the surface of the test, whereas on *S. fairbanksi* they have a slight tendency to be raised.

Geologic horizon.—Sooke beds, Oligocene?

Localities.—Holotype from Slide Hill Beach, Vancouver Island, British Columbia, Leland Stanford Jr. Univ. Dept. Geol. loc., N. P. 131.

SCUTELLA NORRISI Pack

Plate 10, figures 1*a*, 1*b*

Scutella (?) *norrisi* Pack, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 277–278.

Scutella norrisi Pack, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, 1913, pp. 299–300, pl. 15, fig. 1.

Echinarachnius norrisi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Scutella norrisi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 186–187, pl. 85, fig. 9.

Holotype.—No. 11028; *lectotype*, specimen no. 11027, Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of specimen no. 11027: anteroposterior diameter 73 mm., approximate transverse diameter 98 mm., greatest height 7 mm. Marginal outline, in general, subcircular to subpentagonal, but very irregular, due to the presence of broad, deep marginal notches in the ambulacra, the two posterior ones being much greater than the anterior ones; this gives the test the appearance of a maple leaf; the margin is also cut by slight indentations at the sutures between the ambulacral and interambulacral areas. Test very thin, with abactinal surface greatly depressed and rising but little to the apex, which coincides with the apical system. Apical system eccentric slightly to anterior of the center of the test. Madreporic area large, pentagonal, and with four genital pores situated at each of the corners, excepting the odd posterior one. Ambulacra about two-thirds the width of the interambulacra at the ambitus. Ambulacra petaloid. Petals symmetrical, of the same length, and extending about three-fifths the distance to the margin; those of the bivium slightly narrower than those of the trivium. Rows of pores extend in divergent lines for about two-thirds the length of the petal, and then converge very slightly to the end, which gives the petal a nearly wide open appearance; each poriferous area equal to about one-third the width of the interporiferous area. Petals of small specimens are slightly tumid. Inferior surface faintly concave to the mouth. Peristome small, subcircular, and subcentrally located. Broad, deep, straight ambulacral furrows extend to the margin; indistinct branches are given off about two-thirds the distance to the edge of the test. Periproct small, round, and inframarginal, almost marginal.

Related forms.—*Scutella norrisi* is one of the most distinctive Lower Miocene echinoids of California. It resembles *S. andersoni*

Twitchell, but *S. norrisi* may be easily distinguished by its much larger size, relatively more depressed test, inframarginal periproct, usually deeper posterior ambulacral marginal notches which, in some specimens, are of nearly the same relative size, petals wider open at their extremities, and by the fact that the rows of pores converge more at the ends of the petals. It is most closely allied to *S. vaquerosensis* Kew, but differs in having deeper marginal notches and in that the petals are wider open at their extremities.

Geologic horizon.—Vaqueros formation, Lower Miocene, associated with the fauna of the Turritella ineziana zone.

Localities.—Holotype from "Eastern Monterey County, five miles northwest of Stone Canyon Coal Mine" (Pack); lectotype from ". . . near mouth of the Alizo Canyon in the southern end of the San Joaquin Hills, south of Santa Ana, Orange County, California" (Pack), Univ. Calif. loc. 1157; at La Panza, on the San Juan River, and in the mountains between the San Juan River and the Carrizo Plains, San Luis Obispo County, California; Santa Ana Mountains, Orange County, California.

SCUTELLA TEJONENSIS Kew, n. sp.

Plate 12, figures 2*a*, 2*b*

Holotype.—No. 11365 Univ. Calif. Coll. Invert. Pal.

Size small. Measurements of holotype: anteroposterior diameter 26.0 mm., transverse diameter 25.6 mm., greatest height 4.6 mm. Outline of test subcircular, and with broad angular notches in the ambitus in the posterior ambulacral areas; also a distinct notch in the odd interambulacral area; margin rounded. Posterior portion of the surface of the test more depressed than the anterior part. Apical system decidedly eccentric to the anterior, with the summit of the test slightly in front of the latter. Petaliferous portions of the ambulacral areas extend almost to the edge of the test; each poriferous area equal in width to about one-half the interporiferous area. Both outer and inner rows of pores diverge continuously; the inner rows to a greater degree near their distal ends, where they come close to the outer rows; odd anterior petal broader than the others and somewhat elevated. This form of petal contrasts markedly with the petals of other California echinoids, the latter always possessing more or less convergent rows of pores. Inferior surface slightly concave. Peristome round

and slightly eccentric anteriorly. Periproct marginal, of small size, and placed in the posterior interambulacral notch.

Related forms.—This species very closely resembles *Scutella andersoni* Twitchell, with which it is associated, in size, outline, and in the wide and slightly elevated odd anterior petal. It differs in its thicker and more rounded margin; more eccentric apical system; in the flaring appearance of the petals, in contrast to the usually lanceolate type of the former; in that the petals extend nearer the margin; and in the position of the periproct, which is in a distinct marginal notch.

Only one specimen of this species is known. Although quite dissimilar from *Scutella andersoni,* there seems to be a gradation between the two species in the shape of petals, the most distinctive feature. The petals of the bivium in the latter form are often flaring to a slight degree like those of *S. tejonensis.* These forms, including *S. merriami* (Anderson), are probably closely related species.

Geologic horizon.—Vaqueros formation, Lower Miocene. Associated with *S. andersoni* Twitchell.

Locality.—Tejon Hills, Kern County, California, Univ. Calif. loc. 3358.

SCUTELLA VAQUEROSENSIS Kew, n. sp.

Plate 8, figure 3; plate 9, figures 1*a*, 1*b*, 1*c*

Cotypes.—Nos. 11403 and 11404 Univ. Calif. Coll. Invert. Pal. and no. 447 Calif. Acad. Sci. Coll. Pal.

Test large, markedly thin. Measurements of specimen 447: anteroposterior diameter 67 mm., transverse diameter 81.2 mm., greatest height approximately 8 mm. Outline undulating, truncated behind, and rounded anteriorly; transverse diameter greater than the anteroposterior diameter, with greatest breadth immediately posterior to the center of the test; broadly notched in the paired ambulacral areas, slightly so in that of the odd anterior one. Upper surface greatly depressed and rising gently from a very thin margin and nearly flat submarginal area to the apex, the latter being either coincident with the apical system or slightly anterior to it on the odd anterior petal; the greatest elevation is within the area limited by the length of the petals. Apical system slightly eccentric to the anterior. The four genital pores remarkably small. Ambulacra much wider than the interambulacra at the ambitus, that of the odd anterior being twice as wide as the adjoining interambulacra. Dorsal portions of the

ambulacra petaloid. Petals broad, slightly elevated, and extending more than one-half the distance from the apical system to the ambitus; the posterior pair the longest, with the odd anterior pair somewhat shorter than the others. Odd petal differs from the paired ones in that it is considerably wider, and the rows of pores do not tend to converge at their extremities. Inner rows of pores of the paired petals converge slightly near the extremity; outer rows at first diverge and then converge to a greater degree, joining the inner rows at the ends of the petal. Interporiferous area about twice the width of each poriferous area, except in the odd anterior petal, in which it is much wider, though the poriferous area has the same width as in the other petals. Inferior surface nearly flat, faintly concave to the mouth. Peristome round and of comparatively small size. Ambulacral furrows well marked, straight, undivided, and extend to the edge of the test. Periproct round, small, and situated in a small notch in the margin.

Related forms.—This Lower Miocene *Scutella* is most closely related to *Scutella fairbanksi* Arnold, from which it differs in that it is much larger and has a more depressed test, the upper surface is less regularly rounded to the summit, and the periproct is strictly marginal, whereas in the *S. fairbanksi* it is supramarginal. It is separated from *S. norrisi* Pack by having less pronounced triangular marginal notches, and by petals which are not fully open at their extremities.

Geologic horizon.—Upper part of Vaqueros formation, Lower Miocene; associated with *Turritella ineziana* Conrad and *Pecten magnolia* Conrad.

Locality.—Specimen 447 from NE. ¼ of Sec. 16, T. 20 S., R. 6 E., Vaqueros Creek, Monterey County, California, locality 140, Calif. Acad. Sci. Coll. Pal.; cotypes from Salinas River district (Leland Stanford Junior Univ. Coll. Pal.).

Genus ASTRODAPSIS Conrad (emended)

Astrodapsis Conrad. Proc. Acad. Nat. Sci. Phila., vol. 8, 1856, p. 315; U. S. Pac. R. R. Expl., vol. 7, Pal. Rept., 1857, p. 196.

Astrodapsis. Rémond, Proc. Calif. Acad. Sci., vol. 3, 1863, p. 52.

Astrodapsis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 197.

Genotype.—Astrodapsis antiselli Conrad, specimen no. 165466*a* U. S. Nat. Mus.

Test more or less depressed; thickly subdiscoidal to broadly subconical in shape; marginal outline subcircular to subelliptical, with the anteroposterior diameter usually the greater; margin quite thin to very thick and swollen, and with or without notches in the ambulacral and interambulacral areas. Petaliferous areas of the ambulacra more or less elevated. Interambulacral areas more or less depressed; auxiliary groove may be present in the ambulacral areas along the sides of the petals. Petals straight, extending close to the margin, and wide open at their extremities. Poriferous zones nearly parallel, or continuously divergent, or divergent, convergent, and again divergent; ambulacral plates begin to broaden before end of the petal is reached; sporadic pores usually continue to the margin beyond the petal proper. Apical system central or subcentral, more or less depressed; four genital pores present, the odd posterior one being absent. Summit of test central or anteriorly eccentric. Inferior surface flat or concave. Peristome central or subcentral. Periproct round, inframarginal to marginal; never supramarginal. Main ambulacral furrows are usually well marked, broad, and continue from the peristome to the margin, often extending as faint grooves on the upper surface nearly to the apical system and forming a median line on the petals. Indistinct lines or grooves may be thrown off from the main furrows when about two-thirds the distance to the margin, and these usually extend on to the superior surface as sutural lines between the interambulacral and ambulacral areas. Tuberculation prominent, scrobicular, of uniform size, or larger on the petaliferous portions of the ambulacra and inferior surface. Internal structure similar to that of *Scutella;* consists of strong radial partitions which connect with the roof for about one-fourth the distance to the peristome and then continue as ridges on the floor; concentrically placed ridges are placed near the margin, connecting the radial partitions; remainder of the floor more or less roughened.

Discussion.—The early forms of *Astrodapsis,* such as *A. brewerianus* (Conrad), are closely related to *Scutella.* Although this species shows several features characteristic of *Scutella,* nevertheless it is placed in the genus *Astrodapsis* for the reason that it shows a perfect gradation into true astrodapsid forms, *A. brewerianus* var. *diabloensis* and *A. cierboensis. Astrodapsis* is usually distinguished by having either raised petals or depressed interambulacral areas, or both. However, in *A. brewerianus* both of these characters are lacking. On the other hand, it has the rather thickened test, simple ambulacral furrows

(which in most specimens are very indistinct), and petals which reach nearly to the margin, whereas *Scutella* is usually thin, with relatively well developed ambulacral furrows and a wide submarginal area. The genus later becomes more highly developed, the elevation of the petals and the interambulacral depressions becoming more pronounced; finally in the Lower Etchegoin (Jacalitos) formation and the uppermost part of the San Pablo formation a secondary set of grooves is acquired, these being the depressions in the ambulacral areas along the sides of the petals. The ambulacral furrows also become deeper and with distinct branches near the margin, all extending on the upper surface.

The internal structure is similar to that of *Scutella,* having the radial partitions in the interambulacral areas; but, on the other hand, it does not have the degree of complexity of the concentric pillars, these being in some species, such as *A. brewerianus,* poorly developed. Moreover, in *Astrodapsis* the radial partitions do not extend nearly as far in toward the peristome as in *Scutella.*

ASTRODAPSIS ALTUS Kew

Plate 15, figures 4*a,* 4*b*

Astrodapsis altus Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 371–372, pl. 40, figs. 3*a*–3*b*.

Holotype.—No. 10065 Univ. Calif. Coll. Invert. Pal.

Test small. Average measurements: anteroposterior diameter 34.6 mm.; transverse diameter 31.5 mm.; greatest thickness 10.6 mm. Subcircular to subpentagonal in outline; margin thick; superior surface rising immediately from the ambitus to the summit, which is comparatively high and anterior to the apical system, thus giving the test a distinctly conical shape. Ambitus slightly notched in the posterior ambulacral areas. Ambulacra petaloid; petals slightly elevated and wide open. Pores conjugate; inner rows of rounded pores extend to the margin in almost straight lines, converging but little; outer rows of elongated pores converge close to the inner rows near the margin, where they become rounded and continue parallel with the inner rows to the ambitus. Interambulacral areas flat. Anus inframarginal. Inferior surface flat and lacking ambulacral furrows. Tubercles small and set close together.

Related forms.—This form resembles *Astrodapsis tumidus* Rémond, but differs in that the apical system is much more elevated, thus giving the test a more distinctly conical appearance; ambulacral furrows are not present on the under surface, and the superior surface shows no interambulacral depressions. Its conical shape also distinguishes it from the other San Pablo species. It differs from *Astrodapsis cierboensis* Kew in its subpentagonal outline, in contrast to the commonly elliptical outline of the latter; and from *Astrodapsis* (*?*) *pabloensis* (Kew) in its smaller size and the greater thickness of the test.

Geologic horizon.—Upper San Pablo group, Upper Miocene; associated with *Astrodapsis tumidus* Rémond and *Astrodapsis tumidus* (small thick form).

Locality.—Mt. Diablo region, Univ. Calif. loc. 1950 (holotype).

ASTRODAPSIS ANTISELLI Conrad

Plate 19, figures 2*a*, 2*b*, 2*c*

Astrodapsis antiselli Conrad. Proc. Acad. Nat. Sci. Phila., vol. 8, 1856, p. 315; U. S. Pac. R. R. Expl. Rept., vol. 7, 1857, p. 196, pl. 10, figs. 1, 2.

Astrodapsis antiselli. Meek, Smithson. Misc. Coll., vol. 7, no. 183, 1864, p. 2.

Astrodapsis antiselli. Gabb, Calif. Geol. Surv., Pal., vol. 2, 1869, p. 110.

Astrodapsis antiselli. Cooper, Seventh Rept. State Mineralogist California, 1887, p. 270.

Astrodapsis antiselli. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, 1898, pp. 110, 112.

Astrodapsis antiselli. Arnold, Proc. U. S. Nat. Mus., vol. 34, 1908, pl. 35, fig. 10.

Astrodapsis antiselli. Arnold, U. S. Geol. Surv. Geol. Atlas, Santa Cruz folio (no. 163), 1909, pl. 2, fig. 58.

Astrodapsis antiselli. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 702.

Astrodapsis antiselli. McLaughlin and Waring, Calif. State Min. Bur. Bull., no. 69, 1914, map folio, fig. 37.

Astrodapsis antiselli. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 198–199, pl. 94, figs. 3, 4*a*, 4*b*.

Holotype.—No. 165466*a* U. S. Nat. Mus.; *figured specimens,* nos. 11372 and 11373, Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen 11373 Univ. Calif. Coll. Invert. Pal.: anteroposterior diameter 60 mm., transverse diameter 50 mm., greatest height approximately 12 mm. Subcircular to suboval in outline; upper surface considerably depressed; margin thickened and rounded, and with very slight notching in the posterior

ambulacral areas in some specimens. Apical system sunken, central to slightly subcentral, and coinciding with the summit; madreporic area pentagonal; four oval genital pores present, the odd posterior one being absent; five perforated radial plates are situated at the base of the petals. Ambulacra one and a-half times the width of the interambulacra at the margin. Ambulacral areas petaloid. Petals of moderate width and extending close to the edge of the test; poriferous areas very narrow, with correspondingly wide interporiferous area. Odd anterior petal somewhat narrower than the lateral petals. Inner rows of pores round, not converging toward their extremities; outer rows of pores transversely elongate and converging close to the inner rows when about half the distance to the margin, from which point both rows continue in nearly parallel lines to the margin, the double rows diverging from each other when about three-fourths the distance to the margin. Pores conjugated. Petals elevated above the general surface of the test. Interambulacral areas grooved from the apical system to the margin; secondary grooves faintly present along the sides of the petals in the ambulacral areas, which together with the interambulacral depressions form two triangular facets on the surface of the test between the petals. Inferior surface slightly concave. Main ambulacral grooves are straight, broad, and deep near the peristome, and continue over the edge on the upper surface, forming a median line on the petals; the suture between the ambulacral and interambulacral areas is marked by a broad, distinct line on both upper and lower surfaces. Peristome central, large, and circular to subpentagonal in outline. Periproct large, round, inframarginal, and situated near the edge of the test. Tuberculation prominent, consisting of rather large, scrobicular tubercles, which are the same size on both surfaces, except on the depressed portions of the test and in the ambulacral area near the peristome, where they are somewhat smaller; not crowded, but more numerous on the under side. Internal structure consists of heavy radial partitions which reach from the roof to the floor and extend from the inside edge about one-fourth the distance toward the center; disconnected concentric ridges are present in the spaces between the double rows of radial partitions; the remainder of the floor is more or less roughened.

Related forms.—This species differs from *Astrodapsis tumidus* Rémond, which it most closely resembles, in that the interambulacral grooves are shallower, that it has a thicker but relatively more depressed test, less elevated petals, and less numerous but more promi-

nent and larger tubercles. From *A. whitneyi* Rémond it differs in lacking the bell-shaped appearance of the former, in the wider petals, and the much thicker margin. It may be separated from *A. cierboensis* (Kew) by its much larger tubercles and more prominent ambulacral furrows.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene. This species is found associated with *Astrodapsis margaritanus* Kew.

Localities.—Type of Conrad from Estrella, Monterey County, California. It also occurs at Pence Enrico Canyon, Monterey County, Univ. Calif. loc. 2727; mouth of Swains Canyon, north of Bradley, Monterey County (U. S. Geol. Surv. Coll.); two miles south of San Lucas, Monterey County (U. S. Geol. Surv. Coll.); Slacks Canyon, Monterey County (Stanford Univ. Coll.); Wildhorse Canyon, Monterey County (U. S. Geol. Surv. Coll.); three miles above San Lucas (Stanford Univ. Coll.); Scott Valley, Santa Cruz County, California (Stanford Univ. Coll.).

ASTRODAPSIS ARNOLDI, subsp. ARNOLDI (Pack)

Plate 21, figures *3a, 3b, 3c*

Astrodapsis antiselli var. *arnoldi* Pack. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 279–281, pl. 24, figs. 1, 2.

Not *Astrodapsis arnoldi* (Twitchell). Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 199–200, pl. 95, fig. 1.

Holotype.—No. 11030 Univ. Calif. Coll. Invert. Pal.

Test moderately large. Measurements of holotype: anteroposterior diameter 60 mm., transverse diameter 58.6 mm., greatest height 14.9 mm. Outline subcircular, with longitudinal axis slightly longer than the transverse axis; greatest transverse diameter somewhat posterior to the center of the test. Margin rounded and slightly but broadly notched in the ambulacral areas, the degree of notching being greater in the two posterior areas. Upper surface considerably depressed in the submarginal area, from which part it rises markedly to a rather high apex, giving rise to a bell-shaped appearance, as in *Astrodapsis whitneyi* Rémond. Broad, deep depressions exist in the interambulacral areas of the upper surface; smaller ones are present along the sides of the distal portions of the petals in the ambulacral areas. The greatest elevation of the test is on the odd anterior petal immediately in front of the very slightly posteriorly eccentric apical system.

Apical system pentagonal in outline; four large genital pores and five perforated radial plates present. Petals wide; width of each poriferous zone equal to about one-half the width of the interporiferous area; inner rows of pores diverge gradually until about one-half the distance to the margin, when they converge for a short distance and then diverge, continuing with rounded pores to the margin; the initial divergence of the outer rows of slit-like pores is greater than that of the inner rows, and when about two-thirds the distance to the margin converge close to the latter, continuing nearly to the ambitus; pores conjugated. Petals are considerably elevated near the apical system, but become lower toward the margin and in some specimens are nearly flush with the surface of the test in the submarginal area. Odd anterior petal differs from the others in that the inner rows of pores do not converge. Lower surface flat or slightly concave; peristome small, rounded, and slightly eccentric to the posterior, being opposite the apical system. Broad, deep, straight ambulacral grooves are present, which pass through the marginal notches and continue on the petals as a median line or groove; at a point slightly over one-half the distance to the margin auxiliary lines are thrown off which pass to the upper surface as sutural lines between the ambulacral and interambulacral plates. Periproct small, round, and inframarginal, nearly marginal. Tuberculation consists of prominent scrobicular tubercles on the petals and ridges between the grooves on the upper surface, grading into minute ones in the depressions; those on the inferior surface placed close together and nearly as large as the tubercles on the petals.

Related forms.—Pack originally described this form as a variety of *Astrodapsis antiselli* Conrad, calling it *A. antiselli* var. *arnoldi.* Later Twitchell raised it to a species, *A. arnoldi* Twitchell, and included under it a form previously identified by Arnold as *A. whitneyi* Rémond; Twitchell has used the latter as his type. This was entirely erroneous, as the two forms are markedly different. The writer, with considerable material at hand, has deemed it advisable to retain the specific rank of *A. arnoldi,* which according to the rules of nomenclature takes the name *Astrodapsis arnoldi* (Pack). This leaves the form described by Twitchell under *A. arnoldi* nameless. To this the writer has given the name *A. californicus* Kew.

This form differs from *Astrodapsis antiselli* Conrad in having relatively narrower petals which are more elevated, a thinner margin, and a less depressed test; in having a bell-shaped profile, while that

of *A. antiselli* is biscuit-shaped; and in that the poriferous areas of the petals are comparatively wider. From *A. californicus* Kew, the species which Twitchell grouped under *A. arnoldi* (Pack), it may be easily separated, for *A. californicus* is larger, has a thinner test, greatly sunken interambulacral areas, and no grooves along the sides of the petals. In contrast with *A. arnoldi peltoides* (Anderson and Martin), *A. arnoldi* (Pack) has much wider petals, and usually a relatively thicker margin. In general shape it resembles *A. whitneyi* Rémond, but differs in having larger tubercles, a thicker margin, wider petals, and interambulacral and ambulacral grooves. The small grooves along the petals also separate it from *A. tumidus* Rémond.

Geologic range.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Associated with *A. arnoldi* var. *fresnoensis* Kew and A. *arnoldi* var. *depressus.*

Localities.—Holotype from Monterey County, California. Also occurs in the Coalinga District, Fresno County, California, Univ. Calif. loc. 2969 and 2973; Indian Valley, Goat Canyon, and Lynch Creek of the Salinas Valley District, California.

ASTRODAPSIS ARNOLDI DEPRESSUS Kew, n. var.

Plate 23, figures 2*a*, 2*b*, 2*c*

Holotype.—No. 11038 Univ. Calif. Coll. Invert. Pal.

This form is distinguished from *Astrodapsis arnoldi* (Pack) by its depressed test and by not having a bell-shaped appearance like the latter, the upper surface being regularly rounded. Gradations can be found between the two forms, and for this reason only a varietal distinction is made.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Associated with *Astrodapsis arnoldi arnoldi* (Pack) and *Astrodapsis arnoldi* var. *fresnoensis* Kew.

Localities.—Coalinga district, Fresno County, California, Univ. Calif. locs. 2969 and 2973.

ASTRODAPSIS ARNOLDI CRASSUS Kew, n. subsp.

Plate 23, figure 1; plate 24, figures 1*a*, 1*b*, 1*c*

Holotype.—No. 11350 Univ. Calif. Coll. Invert. Pal.

Test moderately large. Measurements of specimen no. 11350: anteroposterior diameter 62 mm., transverse diameter 52 mm., greatest

height 17 mm. Marginal outline suboval to subcircular, with indistinct notches in the posterior ambulacra and a slight lobing of the odd interambulacral area. Upper surface considerably depressed, but regularly arching to a low apex, which is usually a short distance anterior to the center of the test; interambulacra markedly grooved from the apical system to the edge of the test; shallower grooves are present along the sides of the petals in the ambulacral areas. Apical system central. Petals elevated and extending nearly to the margin. Inner rows of pores diverge at first and then continue in approximately parallel lines until close to the edge of the test, when they again diverge slightly; outer rows diverge to a greater degree at first and then converge slightly to the point where the inner rows start to diverge for the second time, and continue parallel to the latter from this point to the margin. In some specimens the inner rows may converge slightly. Poriferous areas narrow, each being about one-fourth the width of the interporiferous area. Actinal surface concave. Peristome central, large, and circular in outline; slightly sunken. Ambulacral furrows deep near the peristome, becoming indistinct near the margin, and then passing into lines which usually extend over the upper surface nearly to the apical system as median lines on the petals; faint lines are given off from the main furrows when slightly over half the distance to the margin, and these continue over the upper surface as sutural lines between the ambulacral and interambulacral plates. Periproct relatively small, sunken, and with the immediate area surrounding it somewhat swollen. Numerous scrobicular tubercles are of the same size on both surfaces, except in the depressed portions of the abactinal side, where they are smaller.

Related forms.—This form is closely related to the other members of the *Astrodapsis arnoldi* group, but may be distinguished by its relatively large peristome, by the posterior lobing in the odd interambulacral area, and by its comparatively narrow petals with the rows of pores in approximately parallel lines.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Localities.—Holotype from south of Pancho Rico Creek in NW. ¼ of Sec. 8, T. 22 S., R. 11 E., Univ. Calif., loc. 3127; also occurs at Lynch Creek, Salinas Valley district, Monterey County, California. A small form of this species occurs at a locality on the Hog Canyon road, Sec. 7, T. 24 S., R. 14 E., Monterey County, California.

ASTRODAPSIS ARNOLDI FRESNOENSIS Kew, n. var.

Plate 23, figures *3a*, *3b*, *3c*

Holotype.—No. 11032 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of holotype: anteroposterior diameter 50.5 mm., transverse diameter 47.3 mm., greatest height 12 mm. Outline from above subcircular; margin thickened and notched in the ambulacral areas, the degree of notching being greater in the two posterior ones. Test somewhat inflated, with the upper surface evenly arched to the summit, which is slightly anterior to the center and near the base of the odd anterior petal. Well marked interambulacral grooves extend from the apical system to the margin, and less prominent grooves are present along the sides of the petals in the ambulacral areas. Apical system comparatively small, and situated in the center of the abactinal surface. Petals of the same size, symmetrical, noticeably narrow, and extending wide open to the margin; in most specimens they are highly elevated near the apical system, but tend to merge with the general surface near the edge of the test. Poriferous areas narrow, each area being about one-third the width of the interporiferous area. Both inner and outer rows of pores extend in slightly diverging lines for about two-thirds the distance to the ambitus and then the double rows diverge to a much greater degree, giving the distal portion of the petals a flaring appearance. Inferior surface concave. Peristome central, relatively small, and round in outline. Ambulacral furrows deep and broad; extend undivided to the ambitus and continue through the marginal notches to form faint median grooves on the petals; about one-half the distance to the margin ambulacral lines are thrown off from the main furrows on the actinal surface, which extend to the upper surface as sutural lines between the ambulacral and interambulacral plates. Periproct inframarginal, and placed about its own diameter from the edge of the test. Tuberculation consists of small, scrobicular tubercles crowded together over both surfaces.

Related forms.—This form may be distinguished by its markedly narrow petals, thick test, and small mouth; these characters separate it from *Astrodapsis arnoldi arnoldi* (Pack), and from *A. major* Kew, which seem to be the most closely allied species.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Associated with *Astrodapsis arnoldi arnoldi* (Pack) and *Astrodapsis arnoldi* var. *depressus* Kew.

Localities.—Coalinga district, Fresno County, California, Univ. Calif. locs. 2969 and 2973.

ASTRODAPSIS ARNOLDI, subsp. PELTOIDES (Anderson and Martin)

Plate 15, figures 2*a*, 2*b*, 3

Astrodapsis peltoides F. M. Anderson and Bruce Martin. Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 4, 1914, pp. 52–53, pl. 2, fig. 2.

Astrodapsis peltoides Nomland. Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, 1916, p. 202 (listed).

Holotype.—No. 102 Calif. Acad. Sci. Coll. Pal.; *topotype,* specimen, no. 451 Calif. Acad. Sci. Coll. Pal.

Size medium. Measurements of holotype: anteroposterior diameter 64.5 mm., transverse diameter 54 mm., greatest height 15.5 mm. Outline of test anteroposteriorly suboval to subcircular; some specimens notched in the ambulacral areas, the degree of notching being greater in the two posterior ones; margins thick, with the upper surface rising immediately to a moderately elevated summit, which is anterior to the center of the test and on the odd anterior ambulacral area. Apical system central; small and flush with the general surface of the test, but depressed below the highest points on the petals. Broad, deep grooves are present in the interambulacral areas, with smaller ones in the ambulacral areas along the outer sides of the petals. Ambulacra wide at the margin, the interambulcra being about one-third the width of the ambulacra; ambulacra petaloid. Petals usually narrow but somewhat variable in width; inner rows of nearly rounded pores diverge but little from the apical system, but on reaching their full extent continue in approximately parallel lines until within about one-fourth the distance from the margin, when they diverge slightly to the edge of the test; outer rows of pores diverge considerably at first and then converge slightly and again diverge, the two rows of pores coming close together when near the edge of the test. Each poriferous zone equal to about one-third to one-half the width of the interporiferous area. Petals more or less elevated, especially near the apical system; usually of the same width, though the odd anterior one may be slightly narrower and the anterior pair somewhat wider than those of the bivium. Inferior surface concave; peristome small, sunken, and

subcircular in outline. Ambulacral furrows well marked, straight, and continuing over the upper surface, in weathered specimens, as sutural lines. Tubercles small, scrobicular, perforated, numerous, and equally distributed on both surfaces of the test.

This species shows a great variety of forms from the same locality. These variations include individuals with margins varying from quite thin to very thick, and from a highly elevated to a depressed test; the petals also vary in their elevation and in width. In as much as gradations can be found between the extremes of the variations all the forms have been included under a single subspecies.

Related forms.—From *Astrodapsis major* Kew, to which it is closely allied, *A. arnoldi peltoides* differs in possessing prominent grooves in the ambulacral areas along the margins of the petals; in that the petals are usually narrower, and the interambulacral depressions are in most specimens not so deep. It can be distinguished from *A. arnoldi arnoldi* (Pack) as being more strongly elliptical in marginal outline; in that the actinal surface shows a greater degree of concavity, and in that the petals are usually narrower. It differs from *A. jacalitosensis* Arnold in having deep interambulacral grooves. From *A. arnoldi crassus* Kew it is distinguished by having a smaller peristome, and usually a more elongate marginal outline; from *A. arnoldi* var. *fresnoensis* Kew, in having a more elongate outline and wider petals. *A. arnoldi spatiosus* Kew may be separated by its extremely wide petals, greatly depressed test, and less strongly elevated petals.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Associated with *Dendraster gibbsii* (Rémond).

Localities.—Holotype from Trophon zone, at head of Zapato Chino Creek, Coalinga district, Fresno County, California, Calif. Acad. Sci. Coll. loc. 293.

ASTRODAPSIS ARNOLDI SPATIOSUS, Kew, n. subsp.

Plate 22, figures 2*a*, 2*b*

Holotype.—No. 11041 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of holotype: anteroposterior diameter 75 mm., transverse diameter 69 mm., greatest height 14.5 mm. Outline subcircular, tending to be slightly pentagonal. Margin notched indistinctly in the posterior ambulacral areas and in the odd posterior interambulacral area, rounded and thickened. Upper surface greatly depressed, gently arching to the summit, which is anterior to the

center of the test and situated on the odd anterior petal. Apical system small and placed very slightly to the posterior of the center of the test. Ambulacra much wider than the interambulacra, the latter being about five-eighths the width of the ambulacra. Petals markedly broad, wide open, and extending to the edge of the test. Odd anterior petal somewhat narrower than the paired petals. Both the inner and outer rows of pores diverge for about one-third their length, converge until about three-fourths the distance to the margin, and then again diverge to the edge of the test; the divergence of the outer rows slightly greater than that of the inner rows, and the poriferous areas gradually narrowing until the two rows are practically united at the margin. Interporiferous areas exceptionally broad, being about three and a-half times the width of each poriferous area. Rows of pores in the odd anterior petal diverge to their maximum, and then continue in nearly parallel lines to the margin, converging but little; both the poriferous area and interporiferous area narrower than in the paired petals; interporiferous area four times the width of each poriferous area. Abactinal surface of the interambulacra characterized by broad, deep depressions extending from the apical system to the ambitus. Indistinct, broad grooves are present along the margins of the petals. Inferior surface slightly concave. In the single specimen at hand the under side is imperfectly exposed. No ambulacral furrows are shown, but branching lines are present which pass to the abactinal side and form a median ridge on the petals and sutural lines between the ambulacral and interambulacral areas. Periproct relatively small and inframarginal; situated about its own diameter from the edge of the test. Tuberculation consists of well defined scrobicular tubercles of fairly large and uniform size over both surfaces.

Related forms.—This form may be easily distinguished from all other similar types by its markedly wide petals, greatly depressed test with thickened margin, and apparent lack of ambulacral furrows; if present they are not well developed. It closely resembles *Astrodapsis antiselli* Conrad and other forms of the Upper San Pablo group (Santa Margarita), but may be separated by its broad, flattened test and more prominent interambulacral grooves.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Locality.—Near Standard Oil Company's well "Powell No. 1," Sargent Canyon, east side of Salinas Valley, Priest Valley quadrangle, California (Standard Oil Co. loc. 41), Univ. Calif. loc. 3572.

ASTRODAPSIS BREWERIANUS (Rémond)

Plate 13, figures *5a, 5b, 5c*

Echinarachnius brewerianus Rémond. Proc. Calif. Acad. Sci., vol. 3, 1863-67, p. 53.
Echinarachnius brewerianus. Meek, Smithson. Misc. Coll., vol. 7, no. 183, 1864, p. 2.
Echinarachnius brewerianus. Gabb, Geol. Surv. Calif., Pal., vol. 2, 1869, pp. 36, 109, pl. 12, figs. 65, *65a*.
Echinarachnius brewerianus. Cooper, Cat. Calif. Fossils: Seventh Rept., State Mineralogist, 1888, p. 271.
Clypeaster ? (Echinarachnius) brewerianus. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, 1898, pp. 109, 118.
Clypeaster brewerianus. Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, 1899, p. 166, pl. 21, fig. 2.
Astrodapsis brewerianus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 702.
Clypeaster brewerianus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 210, pl. 96, figs. *2a–2c*, 3.
Scutella breweriana. B. L. Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 409, 412, 436 (listed).

Neotype.—(Merriam) No. 11016 Univ. Calif. Coll. Invert. Pal.

Test rather small. Measurements of specimen no. 11016: antero-posterior diameter 27.6 mm., transverse diameter 24.5 mm., greatest height 5 mm. Outline subcircular to suboval, margin thickened, rounded, and somewhat broadly notched in the posterior ambulacral areas. Apical system central. Abactinal surface depressed, slightly convex, rising regularly to a low, flattened apex, which is situated on the odd anterior petal near its base. Ambulacral areas wider throughout than the interambulacral areas. Ambulacra petaloid; petals broad, flush with the surface of the test, and extending nearly to the margin; inner rows of rounded pores diverging widely for one-half the distance to the margin, then continuing in nearly parallel lines to the edge of the test; outer rows of elongate pores diverge to a greater degree at first and then converge until close to the inner rows, where they become rounded, continuing to the ambitus; pores conjugate. Interporiferous areas wide, being from three to four times the width of the poriferous areas. Madreporic area small and pentagonal in shape, with large, round genital pores in each corner except the odd posterior one. Actinal surface flat near the margin, concave near the peristome. Ambulacral furrows seldom seen, but when present are broad, straight, and extend nearly to the margin. In one specimen faint branching lines were given off about two-thirds the distance to the edge. Peri-

stome central, round, and slightly depressed. Periproct round, large, and inframarginal, nearly marginal. Test covered with small tubercles of nearly the same size on both surfaces which have sunken scrobicules. Internal structure consists of radial partitions extending from the margin for about one-half the distance toward the center, and continuing as ridges on the floor to the perignathic girdle. No concentric ridges appear to be present.

Related forms.—Although *Astrodapsis brewerianus* resembles the form *A. cierboensis* (Kew), it may be distinguished by the narrower petals, absence of interambulacral depressions, very indistinct or no ambulacral furrows, a relatively more elevated test, and petals which are never raised.

Geologic horizon.—Briones formation, or Astrodapsis brewerianus beds, which lie conformably below the San Pablo group, Upper Miocene, and, with a probable unconformity, above the Monterey group, Middle Miocene.

Localities.—Walnut Creek, Gregory Ranch (?), Contra Costa County, California (figured specimen, J. C. Merriam, 1899); San Pablo Bay, Contra Costa County; Western Pacific R. R. cut, Verona, Pleasanton quadrangle, California (Leland Stanford Jr. Univ. Coll.).

ASTRODAPSIS BREWERIANUS DIABLOENSIS Kew, n. var.

Plate 13, figure 6

Holotype.—No. 11335 Univ. Calif. Coll. Invert. Pal.

This variety differs from *Astrodapsis brewerianus* (Rémond) in that the petaliferous portions of the ambulacra are elevated; that the test grows to be somewhat larger, and the outline is slightly more elongate. All gradations may be found between those having raised petals and those having petals flush with the surface of the test. These are found associated together.

Related forms.—It differs from *Astrodapsis cierboensis* (Kew) in that the petals are narrower and the margin relatively thinner. From *Astrodapsis tumidus* Rémond it may be separated by the lack of interambulacral depressions, in that the ambulacral furrows are not so well developed, and the petals usually are not so highly elevated.

Geologic horizon.—Astrodapsis brewerianus zone, Briones formation, Middle Miocene. Associated with *Astrodapsis brewerianus* (Rémond).

Locality.—One-half mile northeast of Las Trampas Peak, Contra Costa County, California. Type from Univ. Calif. loc. 1191.

ASTRODAPSIS CALIFORNICUS Kew, n. sp.

Plate 18, figure 2

Astrodapsis whitneyi. Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, p. 63, pl. 9, fig. 1.
Astrodapsis whitneyi. Arnold, U. S. Geol. Surv. Bull., no. 398, 1910, p. 94, pl. 33, fig. 1.
Astrodapsis whitneyi. Stefanini, in part, Boll. Soc. geol. italiana, vol. 30, 1911, p. 703.
Astrodapsis arnoldi Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 199–200, pl. 95, fig. 1.

Holotype.—No. 11354 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of specimen no. 11354: anteroposterior diameter 85.8 mm., greatest lateral distance from apical system to margin of test 41.3 mm., greatest height 13 mm. Outline from above subcircular. Margin very thin and rounded; broadly notched in the ambulacral areas, the degree of notching being less prominent in the odd anterior area. Upper surface considerably depressed; submarginal area greatly flattened; petals rise uniformly to summit, whereas in the interambulacral areas the slope of the surface is more gentle near the margin. Broad, deep depressions exist in the interambulacral areas of the superior surface. Ambulacral areas considerably elevated near the center of the test, but become flattened in the submarginal area. Greatest elevation of the test on the odd anterior petal immediately in front of the apical system. Apical system slightly anterior to the center of the test and depressed below the level of the petals. Petals wide, elongate, and nearly reaching the margin, where they are wide open; width of each poriferous zone equal to half the interporiferous area; inner rows of pores diverge gradually until about one-half the distance to the margin, where they continue in parallel lines close to the margin, near which they again slightly diverge. The initial divergence of the outer rows of pores is greater than that of the inner rows, but when about two-thirds the distance to the margin the outer rows converge close to the inner, continuing so to the margin; pores conjugated, slit-like, but becoming rounded near the ambitus. Lower surface concave. Peristome small, rounded, and subcentral. Broad, deep, and straight ambulacral grooves extend from the peristome to the margin. Periproct very small, round, and situated close to the margin on the under side. Tuberculation consists of large scrobicular tubercles on the petals with smaller ones on the interambulacral areas; those on the inferior surface very numerous and about the same size as those on the petals.

Related forms.—This form has been figured by Arnold as *Astrodapsis whitneyi* Rémond, but Twitchell, recognizing that it was a distinct species, described it and gave to it the name *A. arnoldi.* As this name had already been used by Pack in *A. antiselli* var. *arnoldi,* now raised to specific rank of *A. arnoldi,* it is here renamed *A. californicus.* This form differs from *A. whitneyi* in that it has much wider petals; the interambulacral areas are considerably more depressed, the tubercles over the upper surface are not of uniform size, being larger on the petals, and in that it lacks the distinctly bell-shaped appearance. *A. californicus* is most closely allied to *A. coalingensis* Kew, but may be distinguished from it by having wider petals, more deeply depressed interambulacral areas, more highly elevated petaliferous areas, and a larger apical system.

Geologic range.—Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Localities.—Holotype from one mile north of Peerless Oil Co. property, nine miles north of Coalinga, in big oyster beds, Univ. Calif. loc. 3077.

ASTRODAPSIS CIERBOENSIS (Kew)

Plate 14, figures 1*a*, 1*b*, 1*c*

Astrodapsis tumidus subsp. *cierboensis* Kew, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 370–371, pl. 39, figs. 5*a*, 5*b*.

Astrodapsis tumidus subsp. *cierboensis.* B. L. Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 400, 409, 410, 414, 415, 417, 424, 425 (listed).

Cotypes.—Nos. 10061 and 10062 Univ. Calif. Coll. Invert. Pal.

An echinoid of moderately small size. Average measurements: anteroposterior diameter 36 mm., transverse diameter 32 mm., greatest thickness 9.5 mm. Test subcircular to elliptical in marginal outline; strongly depressed; margins thickened and rounded; some specimens slightly notched at the ambitus in the posterior ambulacral areas; abactinal portion of the interambulacral areas may be very faintly depressed along the median line. Upper surface usually somewhat flattened around the center. Summit anterior to the apical system, the latter being central and slightly sunken. Ambulacra petaloid; petals slightly elevated, broad, and wide open at their extremities. Pores conjugate; inner rows of pores diverge widely and then contract slightly about two-thirds the distance from the apical system to the

margin and near the end of the petal; outer rows at first diverge slightly more than the inner rows and then converge markedly at the same point, close to the inner rows; double rows of small, rounded pores extend in nearly parallel lines to the ambitus, and in some specimens on the under surface as a continuation of the pores of the petal proper. Interporiferous areas wide, being about three times the width of each poriferous area. Odd anterior petal narrower than the paired ones. Actinal side concave. Peristome central, small, and subcircular in outline. Periproct small and round; marginal to inframarginal. Ambulacral furrows not usually shown except in occasional specimens, where broad indistinct grooves and bifurcating ambulacral lines are present, the latter extending on the upper surface. In unweathered specimens the tubercles are small but with prominent mamelons, quite numerous, and of the same size on both surfaces.

Related forms.—This form is closely related to *Astrodapsis brewerianus* (Rémond). It differs in possessing broader petals, which are more elevated. It may be separated from *A. brewerianus* var. *diabloensis* Kew in having wider petals with relatively narrower poriferous areas, and in that the interambulacral areas are usually somewhat depressed. From *Astrodapsis tumidus* Rémond it may be distinguished by its wider petals, which are not so strongly elevated; by its usually broader poriferous areas and thicker margin, and in that the ambitus is not so markedly notched in the ambulacral areas; moreover, the interambulacral depressions are usually absent or faint. It may be easily separated from *A. margaritanus* Kew by its more tumid test and wider petals.

Although in a former paper this form was made a subspecies, subsequent investigation has shown that it is entitled to the rank of a species, for the reason that it possesses broader petals than either *A. tumidus* or *A. brewerianus,* and that, although it shows intergradational characters, the constant characters, such as the markedly swollen test, wide petals, and slightly depressed interambulacral areas, distinguish it as a separate species.

Geologic horizon.—Lower San Pablo group, in beds above the Astrodapsis brewerianus zone or Briones formation and below the Astrodapsis tumidus zone. Associated with *Astrodapsis*(*?*) *pabloensis* (Kew).

Locality.—San Pablo Bay and Mount Diablo region. Cotype, specimen no. 10061 from Univ. Calif. loc. 522; cotype, specimen no. 10062 from Univ. Calif. loc. 526.

ASTRODAPSIS COALINGAENSIS Kew, n. sp.

Plate 16, figures 2*a*, 2*b*

Holotype.—No. 11355 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of specimen 11355: anteroposterior diameter 83 mm., transverse diameter 82 mm., greatest height 13.5 mm. Outline subcircular, with distinct notches in the ambulacral areas, those in the posterior areas being larger than the others; the margin also may be slightly indented at the junction of the two areas; margin and submarginal area markedly thin relatively, especially in the larger specimens. Test much depressed and rising gently to a central apex, the major part of the elevation taking place within the area limited by the length of the petals. Apex either coincides with the apical system or is immediately anterior to it. Apical system small and central. Ambulacral star symmetrical. Madreporite subpentagonal, with four genital pores, the odd posterior one being absent; five perforated radial plates present. Ambulacra wide, being broader than the interambulacra at the margin. Dorsal portions petaloid. Petals similar, moderately wide, and extending about two-thirds the distance to the margin; wide open at their extremities; slightly tumid, the tumidity becoming more pronounced toward the apical system; inner rows of rounded pores extend in slightly divergent lines, not contracting toward the ends of the petals except in occasional specimens, and in such individuals the convergence is barely perceptible; outer rows of elongate pores diverge more than the inner rows, and when about half way to the margin converge close to the inner rows, continuing in this manner to the ends of the petals; a few sporadic pores extend beyond, nearly to the margin. Poriferous areas equal about seven-tenths the interporiferous area in the lateral petals; poriferous area somewhat narrower in the odd anterior petal, caused by a slight narrowing of the petal. Interambulacral areas nearly flat, but with very faint, broad depressions. Inferior surface somewhat concave to the peristome. Ambulacral furrows distinct, extending from the peristome to the margin as a straight line and often continuing over the upper surface as a median line on the petals. Peristome subcircular, central, and sunken. Periproct inframarginal, round, small, and situated at or very near the margin. Tuberculation not regular; tubercles on petals relatively large and prominent; on the surface between the petals they are much smaller, becoming very fine and indistinct near the median line of the interambulacral areas; those on the under side as large as those on the petals.

Related forms.—This species is most closely related to *Astrodapsis grandis* Kew, from which it is distinguished by its greater size, relatively more depressed test, and slightly less elevated petals. It differs from *A. californicus* Kew in having narrower petals, a smaller madreporic area, and much less depressed interambulacral areas, those of *A. coalingaensis* Kew being practically flat; the petals of the former continue raised to the margin, whereas in the latter they become flush with the surface when a little over half way to the edge of the test. The nearly flat interambulacral areas distinguish it from all species of the *A. tumidus* group. It differs from *A. whitneyi* Rémond in its less distinctly bell-shaped appearance; in having very slight interambulacral depressions and less elevated petals; the interambulacral plates are more numerous on the abactinal surface; and the tuberculation is not uniform, whereas the tubercles in *A. whitneyi* are small and similar over the entire test, a very distinctive character.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene. Associated with *Astrodapsis grandis* Kew.

Localities.—Holotype from Sec. 12, T. 18 S., R. 14 E., M. D. B. and M., North Coalinga district, Fresno County, California, Univ. Calif. loc. 3076.

ASTRODAPSIS CUYAMANUS Kew, n. sp.

Plate 19, figures 1*a*, 1*b*

Holotype.—No. 11045 Univ. Calif. Coll. Invert. Pal.

Size large. Measurements of holotype: anteroposterior diameter 66 mm., transverse diameter 64.3 mm., greatest thickness 12.5 mm. Test greatly depressed, with margin thin but rounded. Marginal outline subcircular to subovate, with notches in the ambulacral areas and a smaller one in the odd posterior interambulacral area; those in the posterior ambulacral areas greater than the others. Abactinal portion of the interambulacra flat or faintly and broadly depressed. Ambulacra nearly twice the width of the interambulacra at the edge of the test. Apical system central, and somewhat sunken below the general level of the upper surface; situated very slightly anterior to the center of the test. Summit immediately in front of the apical system and located on the odd anterior petal. Petals markedly broad; the interporiferous area being three times the width of each poriferous area; petals of the bivium slightly narrower than those of the trivium;

all wide open at their extremities and extending more than two-thirds the distance to the margin. Inner rows of small, oval-shaped pores extend in continuously divergent lines to the margin; outer rows of slit-like pores diverge and then, when about one-half the distance to the margin, converge close to the inner rows at the end of the petal proper; sporadic pores continue beyond. Petals distinctly elevated, but merge with the submarginal area toward the periphery of the test. Odd anterior petal extends slightly nearer the margins than the others. Inferior surface slightly concave to the peristome. Ambulacral furrows broad, deep, and undivided; extend from the mouth through the marginal notches on the upper surface, where they continue as median grooves on the petals for about one-half the distance to the apical system; indistinct branches are sent off on the under side when about two-thirds of the distance to the margin. Periproct large, round, and inframarginal, nearly marginal. Tuberculation consists of small tubercles, crowded together, and of the same size over both surfaces of the test.

Related forms.—*Astrodapsis cuyamanus* is most closely related to *A. whitneyi* Rémond, having the general shape of the former, but may be separated from it by the greater width of its petals which extend closer to the margin. It also resembles *A. coalingaensis* Kew, but may be distinguished by having small uniform tubercles over the test instead of larger ones on the petals, as in the latter species; also by its wider petals.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene. Associated with *Astrodapsis whitneyi* Rémond.

Locality.—Cuyama Valley, one mile west of ranger's cabin in Branch Canyon, center of NW. ¼ of Sec. 1, T. 9 N., R. 27 W., Santa Barbara County, California, Univ. Calif. loc. 3078.

ASTRODAPSIS FERNANDOENSIS Pack

Plate 24, figures *2a, 2b, 2c*

Astrodapsis fernandoensis Pack. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, p. 279, pl. 24, figs. 3, 4.

Astrodapsis fernandoensis. English, *ibid.*, vol. 8, 1914, pl. 23, fig. 5.

Astrodapsis fernandoensis. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 706.

Astrodapsis fernandoensis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 217–218, pl. 101, figs. 1, 2.

Cotypes.—Nos. 11402 and 11377 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen no. 11042: anteroposterior diameter 51.3 mm., transverse diameter 39.3 mm., greatest height 8.7 mm. Outline suboval, with some forms markedly elongate longitudinally; upper surface much depressed. Margin thickened and rounded; posterior interambulacral area slightly pointed. Apical system somewhat eccentric to the anterior, with summit of the test immediately forward of the former. Ambulacra almost twice as wide as the interambulacra at the margin; ambulacral areas petaloid. Petals large, considerably elevated; those of the bivium somewhat longer than those of the trivium. All wide open and reaching to the margin. Inner rows of rounded pores at first diverge, when about half the distance to the margin converge very slightly, and then diverge again near the edge of the test, continuing in this manner to the ambitus; outer rows of elongate pores, more divergent from the beginning of the petal, converge to a greater degree when half way to the margin, and then continue parallel with the inner rows. Poriferous areas narrow, with a corresponding very wide interporiferous area, the latter being about four times the width of the former. Interambulacral areas possess broad, distinct depressions which extend from the apical system to the margin. Tubercles prominent; primary tubercles large, not numerous, and lacking on the depressed portions of the test; placed in well defined scrobicules; a few secondaries are present, and milliaries are numerous in the intervening spaces. Tubercles of the same size on both upper and lower surfaces, but the primaries more numerous on the actinal side. Inferior surface gently concave; ambulacral furrows not distinct, but when present are straight, undivided, and extend but a short distance from the peristome, gradually passing into lines which continue on the upper surface to form median lines on the petals. Peristome large, round, slightly sunken, and central. Periproct large, oval, inframarginal, and situated its own diameter from the edge of the test.

Related forms.—*Astrodapsis fernandoensis* is unlike ony other species of this genus on account of the presence on the test of the prominent tubercles, which are relatively much larger than those possessed by other forms. This characteristic serves to distinguish it readily from *A. cierboensis* (Kew) and *A. antiselli* Conrad, with which it might be confused.

Geologic horizon.—Lower part of the Fernando formation, Lower Pliocene.

Locality.—Cotypes and figured specimens from Elsmere Canyon, Los Angeles County, California, SW. 1/4 of NW. 1/4, sec. 8, T. 3 N., R. 15 W., San Bernardino B. L. and M., Univ. Calif. loc. 1602.

ASTRODAPSIS GRANDIS Kew, n. sp.

Plate 17, figures 1*a*, 1*b*; plate 18, figure 1

Cotypes.—Nos. 11046 and 11047 Univ. Calif. Coll. Invert. Pal.

Test very large. Measurements of specimen no. 11046: antero-posterior diameter 94 mm., transverse diameter 97 mm., greatest height 15 mm. Upper surface greatly depressed around the submarginal area, with margin markedly thin. Outline subcircular; notches in the ambulacral areas are all of the same size. Upper surface arched regularly to a central apex, the greatest arching taking place within the area limited by half the distance from the margin to the apex. Apical system central, moderate in size, and slightly depressed below the highest elevation of the petals. Ambulacra wide, being broader than the interambulacra at the margin; dorsal portions petaloid. Petals large, symmetrically arranged, extending about two-thirds the distance to the margin; slightly tumid, the tumidity being greatest near the apical system and almost negligible at the ends of the petals. Inner rows of pores small, slightly elongated transversely, the two rows converging but little, if any, toward the extremities of the petal; outer rows converge close to the inner ones when about two-thirds the distance to the end. Abactinal part of interambulacral areas flat, but very faint, broad depressions may be present. Inferior surface slightly concave to the peristome, the latter being central and slightly sunken. Ambulacral furrows distinct, straight, continuing to the margin, and extending over the upper surface nearly to the apex as median lines on the petals; in well preserved specimens faint processes are seen to be given off from the main furrows on the under side about half way to the margin; these also continue over the superior surface along the sutures between the ambulacral and interambulacral plates. Periproct small, round, inframarginal, and situated close to the edge of the test. Tubercles very small over the entire upper surface, and larger and less crowded on the interporiferous area of the petals; on the under side they are larger immediately around the peristome.

Related forms.—This species is most closely related to *Astrodapsis coalingaensis* Kew, but differs in the greater average size; petals not so highly raised; thinner margin; and test relatively less depressed.

From *A. whitneyi* Rémond it differs in having its petals less strongly elevated, and with larger tubercles on them; in its greater size; in having a more nearly circular test with smaller notches in the margin in the posterior ambulacral areas; and in having a relatively more depressed test.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene, above the ''Big Blue'' horizon. Found associated with *Astrodapsis coalingaensis* Kew.

Localities.—North of Coalinga, Fresno County, California. Cotypes from Univ. Calif. loc. 2268.

ASTRODAPSIS JACALITOSENSIS Arnold

Plate 20, figures 1*a*, 1*b*

Astrodapsis jacalitosensis Arnold. U. S. Geol. Surv. Bull., no. 396, 1909, pp. 63–64, pl. 15, fig. 5.

Astrodapsis jacalitosensis. Arnold and Anderson, U. S. Geol. Surv. Bull., no. 398, 1910, p. 111, pl. 37, fig. 5.

Astrodapsis jacalitosensis. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Astrodapsis jacalitosensis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 203–204, pl. 95, fig. 4.

Astrodapsis jacalitosensis. Nomland, Univ. Calif. Publ. Bull. Dept. Geol., 1916, vol. 9, p. 202 (listed).

Holotype.—No. 165610 U. S. Nat. Mus.

Size large. Measurements of specimen no. 11037 Univ. Calif. Coll. Pal.: anteroposterior diameter 67 (?) mm., transverse diameter 79 mm., greatest height 20 mm. Marginal outline suboval, the greatest diameter being usually in the anteroposterior direction; test considerably elevated, rounding concavely from summit to margin, the latter being somewhat thickened and notched in the ambulacral areas. Apical system central and deeply sunken. Petals broad, of the same size, and markedly raised near the summit of the test, but becoming flush with the surface about one-half the distance from the apical system to the margin. Petals wide open, and with very slight tendency to close. Pores continue to the margin, the double rows diverging from each other but little. Interambulacral areas of the upper surface have almost imperceptible broad depressions with faint grooves along the sides of the petals in the ambulacral areas. Inferior surface slightly concave, with distinct broad ambulacral furrows, which extend from the mouth to the edge of the test. Tubercles small, numerous, and of the same size on both actinal and abactinal surfaces. Anus

inframarginal. Mouth central. Broad, deep, straight ambulacral furrows extend from the mouth to the edge of the test.

Related forms.—This form closely resembles *Astrodapsis whitneyi* Rémond, but differs in its larger size, more elongate outline, more elevated petals, more deeply sunken apical system, and in that the petals are of the same width, whereas in the latter species the odd anterior one is broader than the others. It differs from *A. major* (Kew) and *A. arnoldi* (Pack) in that it lacks the interambulacral and ambulacral depressions on the upper surface.

Geologic horizon.—Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Associated with *Dendraster gibbsii* Rémond and *Astrodapsis arnoldi peltoides* (Anderson and Martin).

Localities.—Holotype from ''south of Garza Creek, a mile south of Clark's place,'' Coalinga district, California; specimen no. 11037 from same district, Univ. Calif. loc. 2688.

ASTRODAPSIS MAJOR (Kew), n. sp.

Plate 15, figures 1*a*, 1*b*, 1*c*

Astrodapsis tumidus Kew (*large form*). Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, p. 370, pl. 40, fig. 2.

Cotypes.—Nos. 11003 and 11337 Univ. Calif. Coll. Invert. Pal.

Test large. Average measurements: anteroposterior diameter 53.9 mm., transverse diameter 46.9 mm., greatest thickness 15.1 mm. Outline subcircular, or suboval to subpentagonal. Margin considerably thickened and notched in the ambulacra, the notching being deeper in the two posterior areas. Upper surface greatly depressed, with the apex usually coinciding with the apical system or immediately anterior to it on the odd petal. Apical system is central. Interambulacral areas are deeply and broadly grooved, and extend from the apical system to the margin. A tendency toward faint grooving is present in the ambulacral areas along the sides of the petals. Petals symmetrical, markedly elevated, broad, and extending to the margin. Inner rows of rounded pores diverge until about one-half the distance to the edge of the test, and then either converge slightly or parallel each other to the end; outer rows of elongate pores diverge at first to a greater degree and when about one-third the distance to the margin converge, becoming, near the end of the petal, rounded and close to the inner rows; both rows of pores reach the margin of the test. Each poriferous area at its widest part is equal to about one-third the width of

the interporiferous area. Pores conjugate. Inferior surface nearly flat in the submarginal area, but markedly concave around the peristome. Ambulacral furrows broad, deep, extending to the margin, and throwing off a pair of faint lines slightly over one-half the distance to the edge of the test; the main furrows continue through the marginal notches on the upper surface, and form a shallow median groove on the petals. Tuberculation prominent on unweathered specimens; consists of scrobicular, perforated tubercles of moderate size; similar on both surfaces except in the interambulacral depression on the abactinal side, where they are somewhat smaller. Peristome round, sunken, posteriorly slightly eccentric or central. Periproct small, round, inframarginal, and situated on the lower surface a distance equal to its own diameter from the edge of the test.

Related forms.—This species is closely related to *Astrodapsis tumidus* Rémond, being one of the most highly developed members in this evolutionary series. It may be distinguished from the latter by its uniformly greater size, thicker margin, deeper interambulacral grooves, usually more elevated petals, and more deeply concave inferior surface. It is most closely allied to *A. arnoldi peltoides* (Anderson and Martin), differing in that it lacks the marked grooves in the ambulacral areas along the sides of the petals; and in that the petals are usually wider. It may be separated from *A. arnoldi* (Pack) in lacking the grooves along the sides of the petals; in that the poriferous areas of the petals are narrower; in lacking the usually characteristic bell-shaped appearance of *A. arnoldi,* and in that the lower surface is much more strongly concave. *A. margaritanus* Kew differs in having a markedly depressed test and in that the petals are not so highly elevated.

Geologic horizon.—Uppermost San Pablo group, above the fresh water horizon of this series, Lower Pliocene; probably equivalent to Lower Etchegoin (Jacalitos).

Localities.—San Pablo Bay-Mount Diablo region of Middle California. Cotypes from Univ. Calif. loc. 1742.

ASTRODAPSIS MARGARITANUS Kew, n. sp.

Plate 22, figures 1*a*, 1*b*

Cotypes.—Nos. 11023 and 11035 Univ. Calif. Coll. Invert. Pal.

Size moderate. Average measurements of specimen 11023: anteroposterior diameter 61.5 mm., transverse diameter 52.6 mm., greatest height 11.5 mm.; of specimen no. 11035: anteroposterior diameter 58.7

mm., transverse diameter 36.8 mm., greatest height 7.5 mm. Outline of test oval to subpentagonal, the greatest diameter being in the anteroposterior direction; margin relatively thin; upper surface greatly depressed, nearly flat, but rising gently to a low apex situated on the odd anterior petal immediately in front of the apical system; interambulacral areas sunken into broad indistinct grooves. Marginal notches in the ambulacral areas are usually present, the notches being deeper in the two posterior areas. Apical system central. Ambulacral areas wider, being one and a-half times the width of the interambulacral areas at the margin. Petals symmetrical; inner rows of pores diverging gradually nearly to the margin; outer rows diverging and then slightly converging until they almost merge with the inner rows close to the edge of the test. Odd anterior petal narrower than the others, with the anterior pair slightly wider than the posterior two. Interporiferous area very wide, being about four times the width of each poriferous area. Petals prominently elevated. Lower surface concave to the peristome, which is central. Ambulacral furrows, broad, deep, extending to the margin, and continuing as faint lines through the notches on the upper surface as median lines on the petals for about one-half the distance to the apical system. Tubercles on the upper surface of moderate size, scrobicular, numerous, and slightly smaller in the depressed regions of the interambulacral areas. Periproct small, round, and situated close to the margin on the inferior surface.

Related forms.—This form belongs to the *Astrodapsis antiselli* Conrad group, and appears to represent a stage of evolutionary development equivalent to that of *Astrodapsis cierboensis* (Kew) from the Lower San Pablo group. It differs in having narrower petals; a thinner test; in that it possesses interambulacral grooves; and in that it attains a greater size. Its most distinctive character lies in the fact that it has a remarkably flat test, with distinctly raised petals. It differs further from *A. antiselli* Conrad by the smaller size of its tubercles and in its greatly depressed test.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene. Associated with *Astrodapsis tumidus* Rémond and *A. whitneyi* Rémond.

Localities.—Cotypes from type locality for the "Santa Margarita" (San Pablo) formation, near the town of Santa Margarita, San Luis Obispo County, California, Univ. Calif. locs. 1697 and 1707. Mouth of Swain's Canyon north of Bradley, Monterey County, California (U. S. Geol. Surv. Coll.).

ASTRODAPSIS ORNATUS Kew, n. sp.

Plate 21, figures 1*a*, 1*b*, 1*c*, 1*d*

Cotypes.—Nos. 11374 and 11375 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen no. 11374: antero-posterior diameter 44.7 mm., transverse diameter 42.7 mm., greatest height 11 mm. Outline from above subpentagonal; margin thick and notched in the ambulacral areas, the notching being greater in the two posterior ones. Apical system symmetrical and eccentric to the anterior. Upper surface distinctly elevated, giving the test a broadly subconical shape. The apex is immediately anterior to the apical system. Ambulacral areas broader than the interambulacral areas at the margin; ambulacra petaloid. Petals considerably elevated, narrow, and wide open at their extremities. Inner rows of rounded pores after reaching their fullest divergence continue in straight lines to the ends of the petals, with no tendency to converge; outer rows of transversely elongate pores when about one-half the distance to the margin converge close to the inner rows, and then continue parallel with the latter to the end. Due to the slight eccentricity of the apical system the petals of the trivium extend nearly to the margin, the odd anterior one reaching the edge of the test, while those of the bivium extend a little over three-fourths the distance to the margin. Interambulacral plates on the upper surface are heavy, large, and ornamented by greatly swollen edges, and in the center of the depressed portion of the plate by a small elevation, or boss, which corresponds in shape to the plate itself; the ambulacral plates of the upper surface are swollen along their edges, the enlargement being greater at their junction with the plates of the interambulacra, so that it gives the appearance of a double line extending along the suture from the margin toward the apical system. All the plates of the under surface possess a thickened border. This ornamentation is only visible in specimens which have been slightly weathered, and is a very distinctive feature. The inferior surface is markedly concave, and with deep, broad, undivided ambulacral furrows extending from the peristome to the margin. Peristome small, central, or slightly eccentric to the posterior. Periproct small, round, and situated close to the edge of the test on the lower surface.

Related forms.—*Astrodapsis ornatus* is closely related to the other species of this genus occurring in the Upper San Pablo group (Santa Margarita formation). It closely resembles *A. tumidus* Rémond, with

which it is often found associated, but may be distinguished by its distinctly pentagonal marginal outline; relatively narrower petals; deeper interambulacral depressions on the upper surface; more elevated petals; and a test broadly subconical in shape. From *A. altus* Kew it differs in having interambulacral depressions, and from *A. antiselli* Conrad in having a thinner margin and a pentagonal outline. The ornamented plates which are developed on the slightly weathered specimens usually serve to distinguish it.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene. Occurs with *Astrodapsis whitneyi* and *A. tumidus* (*small, thick form*).

Localities.—San Juan River district, Univ. Calif. loc. 2721 (cotypes), and Quailwater Canyon, San Luis Obispo County, California (U. S. Geol. Surv. Coll.); Slack's Canyon, Monterey County, California (Stanford Univ. Coll.).

ASTRODAPSIS (?) PABLOENSIS (Kew)

Plate 14, figures 2*a*, 2*b*, 2*c*

Scutella pabloensis Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, p. 369, pl. 39, figs. 6*a*, 6*b*.

Scutella pabloensis. B. L. Clark, *ibid.*, pp. 400, 403, 417, 425 (listed).

Holotype.—No. 10063 Univ. Calif. Coll. Invert. Pal.

Size medium. Average measurements: anteroposterior diameter 42.2 mm., transverse diameter 40.5 mm., greatest thickness 8 mm. Test thin and greatly depressed. Outline of test subcircular; transverse diameter usually greater than the anteroposterior diameter; posterior interambulacral area strongly lobed; ambitus notched in the ambulacral areas, the degree of notching being greater in the two posterior areas; margin thinner behind. Upper surface rising gradually to the summit, which is anterior to the apical system, the latter being central. Interambulacra flat. Ambulacra petaloid; petals slightly elevated, wide open at their extremities, and extending about three-fourths the distance from the apical system to the margin. Pores conjugate; inner rows of rounded pores diverge gradually until about one-third the distance to the ambitus, and then converge slightly to the end of the petal; outer rows of elongate pores diverge somewhat more than the inner rows and continue in this manner for over one-half the distance to the end of the petal, when they converge quite close to the inner rows at the end; double rows of small, round pores diverge from the end of the petals to the ambitus. Poriferous areas wide, being about one-fourth the width of the petal; areas between

the petals flat. Inferior surface slightly concave. Prominent, broad ambulacral furrows are present, which extend undivided from the peristome to the margin. Peristome small, subcircular in outline, and central. Periproct small, round, and placed in a small notch in the margin. Tubercles scrobicular, very small, numerous, and similar on both sides of the test.

Related forms.—*Astrodapsis* (*?*) *pabloensis* (Kew) may be distinguished from the forms of the Astrodapsis tumidus group by its much thinner and more depressed test, and by the posterior lobing of the margin. It differs from *Scutella fairbanksi* Arnold in that the petals are narrower and extend nearer the margin, and in that the anus is marginal, and not supramarginal as in *S. fairbanksi*. *Scutella gabbi* Rémond (*large form*) somewhat resembles it, but differs in lacking raised petals.

Geologic horizon.—Above the Scutella gabbi zone, Lower San Pablo group, Upper Miocene. Associated with *Astrodapsis cierboensis* (Kew).

Localities.—Holotype from south of San Pablo Bay, near Hercules, Univ. Calif. loc. 232; near Layfayette, Contra Costa County, California; south side of Mount Diablo, Contra Costa County, California.

ASTRODAPSIS SCUTELLIFORMIS Kew, n. sp.

Plate 21, figure 2

Holotype.—No. 11048 Univ. Calif. Coll. Invert. Pal.

Test much depressed and rather small. Measurements of holotype: anteroposterior diameter 27.3 mm., transverse diameter 25.0 mm., greatest height 5 mm. Outline subcircular, with marginal notches at the ambitus in the ambulacral areas, the posterior ones being more prominent than the others; test relatively thick in the smaller specimens, with the margin markedly so. Apex central and coinciding with the apical system. Petals broad, nearly symmetrical, extending close to the margin; inner rows of pores do not tend to converge, but continue in approximately parallel lines for two-thirds the distance to the margin, where they assume a greater angle of divergence which continues to their end; the outer rows diverge more at first, but when two-thirds of the distance to the margin converge close to the inner rows and continue so to the end of the petal. Width of poriferous areas equal to three-fifths that of the whole petal; petals very slightly raised. Ambulacra somewhat wider than the interambulacra at the margin. The under surface not well exposed; slightly

concave, with well marked but shallow ambulacral furrows, which extend undivided to the margin. Tuberculation distinct; tubercles relatively large, of the same size on both surfaces, not numerous, and placed in well defined scrobicules; mamelons of the tubercles on the petals slightly larger; small tubercles present in the interspaces. Periproct rather large, and placed immediately below the ambitus.

Related forms.—This species resembles closely the young specimens of *Astrodapsis coalingaensis* Kew, but may be distinguished readily by the large size of the tubercles over both surfaces and by the relatively thicker test. From *Scutella merriami* (Anderson) and *S. andersoni* Twitchell it may be distinguished by its scrobicular tubercles, less undulating margin, and in that the anterior part of the upper surface is not elevated. From *S. gabbi* (Rémond) it differs in not having a slightly supramarginal periproct, and in that the petals do not tend to close.

Geologic horizon.—Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Localities.—Holotype from north of Coalinga, Fresno County, California, Univ. Calif. loc. 2354.

ASTRODAPSIS TUMIDUS Rémond

Plate 14, figures *3a, 3b, 3c, 4a, 4b*

Astrodapsis tumidus Rémond. Proc. Calif. Acad. Sci., vol. 3, 1863, pp. 52, 53, no figure.

Astrodapsis tumidus. Meek, Smithson. Misc. Coll., vol. 7, no. 183, 1864, p. 2.

Astrodapsis tumidus. Gabb, Geol. Surv. Calif., Pal., vol. 2, 1869, pp. 37, 110, pl. 13, figs. 68, 68*a*.

Astrodapsis tumidus. Cooper, Cat. Calif. Fossils, Seventh Rept. Calif. State Mineralogist, 1888, p. 270.

Astrodapsis tumidus. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, 1898, no. 4, pp. 110, 111, 112, 117 (listed).

Astrodapsis tumidus. Merriam, Proc. Calif. Acad. Sci., ser. 3, vol. 1, no. 5, 1899, pp. 166–167, pl. 21, fig. 3.

Astrodapsis tumidus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Astrodapsis tumidus. B. L. Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, 1912, p. 54 (listed).

Astrodapsis tumidus. Kew, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pp. 366, 367, 370, pl. 39, figs. 7*a*, 7*b*, 7*c*; pl. 40, figs. 1*a*, 1*b*, 2.

Astrodapsis tumidus. B. L. Clark, *ibid.*, pp. 400, 401, 404, 410, 411, 415, 417, 424, 425, 426 (mentioned in text and lists only).

Astrodapsis tumidus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 202–203, pl. 95, figs. 3*a*, 3*b*; pl. 108, fig. A.

Neotype (Merriam).—No. 11329 Univ. Calif. Coll. Invert. Pal.; *figured specimens,* nos. 11006, 11008, Univ. Calif. Coll. Invert. Pal.

Test small. Average measurements: anteroposterior diameter 36.5 mm., transverse diameter 30.4 mm., greatest thickness 8.8 mm. Test depressed, subcircular to suboval in outline. Margin tumid and distinctly notched at the ambitus in the ambulacra, the notching being deeper in the two posterior areas. Superior surface usually regularly arched to the summit, but in some specimens the submarginal area is slightly flattened. Apex coincides with, or is immediately anterior to the apical system. The majority of specimens have a marked depression or median groove in the interambulacral areas which extends from the margin to the summit. Apical system central; madreporic area pentagonal, with four genital pores present, the one opposite to the posterior interambulacral area being absent. Petals prominently elevated and extending, wide open, to the edge of the test. Pores conjugate; inner rows of rounded pores only slightly converge near the margin, whereas the outer rows of elongate pores distinctly converge; when about three-fourths the distance to the ambitus, the two rows of pores become rounded and continue in parallel lines to the margin. Interporiferous areas wide, being about four times the width of the poriferous areas; odd anterior petal is slightly narrower and less constricted than the others. Inferior surface more or less concave to the peristome. Mouth sunken, central, large, and subpentagonal in outline. Ambulacral furrows distinct, broad, branching a little over half the distance to the margin, and extending through the marginal notches to the upper surface, where the main furrows form indistinct median grooves on the petals; suture lines between the interambulacral and ambulacral plates are formed by the extension of the branching ambulacral lines. Periproct large, round, and situated close to the margin on the under surface. Tuberculation distinct; tubercles scrobicular, of medium size, and similar on both surfaces except that they are somewhat smaller in the depressions of the superior surface. Internal skeleton consists of strong, radially placed partitions in each ambulacral area, which reach to the roof for about one-fourth the distance from the ambitus to the peristome, and continue to the mouth as low ridges on the floor of the test; a few concentric ridges are present near the edge of the test, connecting the radial partitions; remainder of the floor more or less roughened.

Variations.— A *small thick form* is characterized by a smaller test, (average measurements: anteroposterior diameter 27.8 mm., transverse diameter 24.6 mm., greatest thickness 8.6 mm.); in being relatively thicker with a tumid margin; and in having the superior surface more evenly rounded in profile. Gradations may be found between the typical *Astrodapsis tumidus* Rémond and this form.

Related forms.—*Astrodapsis tumidus* Rémond is distinguished from *A. cierboensis* (Kew) by its narrower and less closely constricted petals, which are more strongly elevated, and in that it possesses interambulacral depressions. The typical *A. tumidus* further differs in having a thinner margin. From *A. major* Kew it may be separated by its smaller test; relatively shallower interambulacral depressions; in that the under surface is usually not so strongly concave; and by its comparatively thinner margin. The *A. tumidus* (*small thick form*) has a relatively more elevated and more strongly convex upper surface. It can be distinguished from *A. altus* Kew in that it lacks the distinctly conical test of the latter, and possesses interambulacral depressions. *A. whitneyi* Rémond can easily be separated from *A. tumidus* Rémond owing to its much thinner margin, narrower petals, and by its distinctly bell-shaped appearance. From the Lower Etchegoin (Jacalitos) species, *A. arnoldi peltoides* (Anderson and Martin) and *A. arnoldi* (Pack), it is readily distinguished by the absence of grooves in the ambulacral areas along the sides of the petals. It differs from the former by having wider petals, and from the latter in being of smaller size and in having relatively narrower poriferous areas in the petals.

Geologic horizon.—Specimens of the typical *Astrodapsis tumidus* Rémond are found abundantly in the lower part of the upper San Pablo group in association with *A. whitneyi* Rémond and *A. altus* Kew. The *small thick form* occurs in the middle part of the Upper San Pablo group, together with *Scutella gabbi* (Rémond) (*notched form*). Both forms are present in the upper part of the "Santa Margarita" formation, associated with *A. whitneyi* Rémond and *A. ornatus* Kew.

Localities.—Type (Rémond) and neotype (J. C. Merriam, 1899, specimen no. 11329 Univ. Calif. Coll. Invert. Pal.) from south side of San Pablo Bay. Also common in Mount Diablo region of Middle California; at the type locality of the "Santa Margarita" formation near the town of Santa Margarita, San Luis Obispo County, California; and Carnaza Creek, and San Juan River district, San Luis Obispo County, California.

Holotype of *small thick form*, from San Pablo Bay-Mount Diablo region (specimen no. 11006 Univ. Calif. Coll. Invert. Pal.); near town of Santa Margarita, San Luis Obispo County, California; Quailwater Canyon, San Luis Obispo County, California (U. S. Geol. Surv., Calif. Acad. Sci., and Univ. Calif. collections).

ASTRODAPSIS WHITNEYI Rémond

Plate 16, figures 1*a*, 1*b*; plate 17, figure 2

Astrodapsis whitneyi Rémond. Proc. Calif. Acad. Sci., vol. 3, 1863, p. 52.
Astrodapsis whitneyi. Meek, Smithson. Misc. Coll., vol. 7, no. 183, 1864, p. 2.
Astrodapsis whitneyi. Gabb, Calif. Geol. Surv., Pal., vol. 2, 1869, pp. 37, 110, pl. 13, figs. 67, 67*a*.
Astrodapsis whitneyi. Cooper, Seventh Rept. Calif. State Mineralogist, 1888, p. 271.
Astrodapsis whitneyi. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, 1898, pp. 110, 111, 112, 117 (cited).
Astrodapsis whitneyi. Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, 1899, p. 167, pl. 21, figs. 4, 4*a*.
Not *Astrodapsis whitneyi*. Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, p. 63, pl. 11, fig. 1. See *A. californicus*.
Astrodapsis whitneyi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.
Astrodapsis whitneyi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 201–202, pl. 95, figs. 2*a*–2*c*.
Astrodapsis whitneyi. B. L. Clark, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1915, pl. 42, fig. 1 (figure only).
Astrodapsis whitneyi. Kew, *ibid.*, p. 372, pl. 40, fig. 4.

Heautotype.—No. 11004 Univ. Calif. Coll. Invert. Pal.

Test of moderately large size. Measurements of specimen 11004: anteroposterior diameter 62.4 mm., transverse diameter 61.8 mm., greatest height 11.5 mm. Outline subcircular; margins thin; submarginal area nearly flat, with superior surface strongly arched from the extremities of the petals to the apical system, giving the test a bell-shaped appearance. Margin notched in the ambulacral areas, the two posterior notches being broader and deeper than the others; summit coincides with apical system. The latter is slightly eccentric to the anterior of the center. Four genital pores and five perforated radial plates present. Ambulacra wider than the interambulacra at the ambitus; ambulacra petaloid. Lateral petals narrow, distinctly elevated, wide open at their ends, and extending nearly to the margin. Inner rows of rounded pores after first diverging extend in almost straight lines, converging slightly about three-fourths the distance to the margin; outer rows of transversely elongate pores

diverge strongly at first and then converge markedly about three-fourths the distance to the margin, at which point they become rounded and continue parallel with the inner rows to the end of the petal. Width of interporiferous areas of lateral petals over one-half the breadth of the entire petal. Odd anterior petal of the same length and wide open at its extremity, as in the lateral petals, but differs somewhat from the others in that it is wider, due to the greater width of the interporiferous area; extends closer to the margin, and is slightly less elevated than the others. Inferior surface concave to the peristome; marked by distinct, straight, undivided ambulacral furrows, which in some specimens pass through the marginal notches on the upper surface and continue nearly to the apical system, forming a slight median groove on the petal. Peristome subcentral, small, and subcircular in outline. Periproct small, round, and inframarginal, nearly marginal. Tubercles small, crowded, and similar over both surfaces.

Related forms.—*Astrodapsis whitneyi* Rémond differs from *A. tumidus* Rémond mainly in its much thinner margin; smaller tubercles; relatively less pronounced widening of the ambulacral plates toward the ambitus; flat interambulacral areas; and in its characteristic bell-shaped appearance. *A. whitneyi* seems to be very closely allied to the southern form *A. coalingaensis* Kew, but it is readily distinguished from the latter by having a smaller though relatively higher test; in that the tuberculation is uniform over the surface, while in *A. coalingaensis* the petaliferous areas support larger tubercles; in that the posterior marginal notches are comparatively deeper; and in that the periproct is situated nearer the margin. Twitchell entertains doubt as to the dissimilarity between *A. whitneyi* and *A. californicus* Kew, but the latter may be separated by its deep, broad depressed interambulacral areas, which in *A. whitneyi* are flat; also the petals are much wider and the marginal notches are shallower.

Geologic horizon.—Upper portion of the San Pablo group, Upper Miocene, occurring with *Astrodapsis tumidus* Rémond and *A. altus* Kew; and "Santa Margarita" formation associated with *A. tumidus* and *A. ornatus* Kew.

Localities.—San Pablo Bay and Mount Diablo regions, California. Type of Rémond from Walnut Creek, Contra Costa County, California. Figured specimens from Univ. Calif. loc. 1227. Also from San Juan River district, and Quailwater Canyon, San Luis Obispo County, California; Cuyama River district (U. S. Geol. Surv. Coll.); Salinas River district (U. S. Geol. Surv. Coll.).

Genus DENDRASTER Agassiz

Dendraster L. Agassiz. Catalogue Raisonné des Echinides; Ann. de des sci. nat., ser. 3, vol. 7, 1847, p. 135.

Echinarachnius A. Agassiz (subgenus), in part, Revision of the Echini, Mus. Comp. Zoöl. Illus. Cat., no. 7, pt. 1, 1872, pp. 107, 315, 524.

Echinarachnius. Duncan (subgenus), in part, Revision of the genera and great groups of Echinoidea; Proc. Linn. Soc. London, vol. 28, 1891, p. 158.

Echinarachnius. Grabau and Shimer, North American index fossils, 1910, p. 592.

Dendraster. Clark and Twitchell, emend., Mesozoic and Cenozoic Echinodermata of the United States, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 190.

The genus *Dendraster* is used here as Agassiz originally defined it. His description, translated from the French, is as follows:

Form subcircular, depressed. Ambulacral star eccentric to the posterior. Petals rounded and unequal; the odd one longer than the anterior ambulacral pair. Ambulacral furrows of the inferior surface very ramified, encroaching even on to the upper surface. Anus inframarginal as in the scutellas. Four genital pores. Differing from the scutellas by its eccentric ambulacral star.

DENDRASTER ARNOLDI Twitchell

Plate 28, figures 2*a*, 2*b*, 2*c*

Astrodapsis ? sp. *a* Arnold. U. S. Geol. Surv. Bull., no. 396, 1909, p. 162, pl. 28, figs. 3, 3*a*.

Astrodapsis ? sp. *a*. Arnold and R. Anderson, U. S. Geol. Surv. Bull., no. 398, 1910, p. 338, pl. 50, figs. 3, 3*a*.

Dendraster arnoldi Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 192–193, pl. 88, figs. 4*a*, 4*b*, 4*c*, 4*d*.

Holotype.—No. 165707 U. S. Nat. Mus.; *figured specimens,* no. 165701 U. S. Nat. Mus. and 11384 Univ. Calif. Coll. Invert. Pal.

Test small. Average measurements: anteroposterior diameter 28.7 mm., transverse diameter 28.1 mm., greatest height 7.2 mm. Outline subcircular, with its greatest lateral diameter slightly posterior to the center; very slightly notched in the ambulacral areas. Test moderately thickened, but much depressed; margin thick and with upper surface regularly arched to the summit, the latter being anterior to the center and to the apical system. Superior surface possesses faint interambulacral grooves, which may or may not be present in all specimens. Apical system slightly eccentric to the posterior of the

center of the test, the amount of eccentricity being less than one-seventh the radius of the test. Ambulacra wider than the interambulacra at the ambitus. Petals of moderate width and extending about two-thirds the distance to the margin. Petals of the bivium shortest, with the odd anterior one longer than the two anterior lateral ones. Pores oval and conjugated, rows of pores diverging relatively rapidly at first and then continuing to the ends of the petals, converging but little at their extremities; the anterior rows of the lateral petals are curved considerably more than the posterior rows, which in some specimens are nearly straight. All the petaliferous areas are distinctly tumid. Poriferous zones wide, each being equal to about two-thirds the width of the interporiferous area. Madreporic area large; four large genital pores present and also five radial plates, each perforated by a small pore. Inferior surface concave to the peristome. Mouth posteriorly eccentric and situated approximately opposite the apical system. Ambulacral furrows broad, well marked, branching dichotomously a short distance from the peristome and continuing to the margin. Periproct small, round, inframarginal, and situated a distance equal to its own diameter from the edge of the test. Tubercles scrobicular and prominent; those of the upper surface are larger on the petaliferous area, whereas those on the remainder of the upper surface are smaller, but increase in size toward the marginal area. Tubercles on the inferior surface deeply scrobicular and of the same size as those on the petals, except in the ambulacral furrows, where they are markedly smaller. The internal structure consists of radial partitions extending inward about one-third the distance to the center with a few broad supports near the margin arranged concentrically in the ambulacral areas between the partitions; the remaining portion of the floor is smooth. Auricles low but heavily built and connected at their base by a low, broad ridge surrounding the edge of the actinostome. Jaws clypeastroid in character and rather flat.

Related forms.—*Dendraster arnoldi* in general appearance resembles *D. perrini* (Weaver), but differs from the latter in that the tubercles are relatively smaller and of the same size over the test, whereas in the former they are prominent, deeply scrobicular, and vary in size, those on the interporiferous areas of the petals being larger than those outside; the petals are more symmetrical and comparatively broader in *D. perrini;* and as a whole the test is larger and thicker.

From *D. coalingaensis* Twitchell it differs in having a more elevated test, with the upper surface regularly arched; a less eccentric apical system; in that the periproct is situated nearer the edge of the test; and in that the petals are always more or less tumid.

Geologic horizon.—Upper Etchegoin formation, Middle Pliocene. Associated with *Dendraster perrini* (Weaver).

Localities.—Holotype from ''south of Lucille well, two miles southwest of Coalinga;'' also occurs on Pajaro River one and a-half miles southwest of Chittenden, near Sargent Oil Field, Santa Cruz County, California, Univ. Calif. loc. 3129.

DENDRASTER ASHLEYI (Arnold)

Plate 27, figures 1*a*, 1*b*, 1*c*

Echinarachnius ashleyi Merriam (MS.), Arnold. U. S. Geol. Surv. Bull., no. 322, 1907, p. 58, pl. 24, figs. 6, 7.

Dendraster ashleyi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 706.

Scutella ashleyi. McLaughlin and Waring, Calif. State Min. Bur. Bull., no. 69, 1914, map folio, fig. 43.

Holotype.—No. 165259 U. S. Nat. Mus.; *figured specimen* no. 11043 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen no. 11043: anteroposterior diameter 62.5 mm., transverse diameter 74 mm., greatest height 6 mm. Markedly thin. Marginal outline subquadrate, the posterior margin being broadly truncated; transverse diameter the greater, with its greatest width in the posterior portion of the test. Upper surface rises gently to the summit, which is posterior to the center of the test and in front of the apical system; greatest elevation within the radius of the length of the petals. Apical system situated far back near the posterior margin. Madreporite pentagonal in outline, with four genital pores opposite the four anterior corners. Lateral petals not symmetrical, the anterior rows of pores in each petal being curved to a greater degree than those of the posterior rows. Petals of the bivium relatively short, and diverging so as to form with their axes an angle of nearly 180 degrees. Poriferous areas comparatively wide, each being about one-half the width of the interporiferous area. Petals of the trivium of the same length; lateral ones somewhat narrower than the odd anterior one. Poriferous areas of the anterior lateral petals equal to about one-half to one-third the width of the inter-

poriferous area; poriferous areas of the odd petal exceedingly narrow, each being about one-eighth the width of the interporiferous area. Inferior surface very slightly concave to the peristome. The latter is small and round. Dichotomously branching ambulacral furrows extend in well marked lines from the peristome to the margin, but become less distinct toward their extremities, especially those of the odd anterior set. Periproct small, subcircular, inframarginal, and placed about twice its own diameter from the edge of the test. Fine tubercles entirely cover the test. The test of this species is relatively more elevated in the younger than the older specimens.

Related forms.—*Dendraster ashleyi* may be distinguished from *D. gibbsii* (Rémond) by its thinner test; and from other dendrasters by its extremely eccentric apical system and widely divergent petals of the bivium. It is closely allied to *D. gibbsii*, from which it probably descended.

Geologic horizon.—Upper Etchegoin and Upper Fernando formations, Middle and Upper Pliocene.

Localities.—Figured specimen from Purisima Hills near Lompoc, Santa Barbara County, California, Univ. of Calif. loc. 3130 (Standard Oil Co. loc. 344); Graciosa Ridge near Orcutt (Arnold type); Sargent Oil Fields, Santa Clara County; Coalinga district, Fresno County, California.

DENDRASTER ASHLEYI YNEZENSIS Kew, n. var.

Plate 36, figures 2*a*, 2*b*

Holotype.—No. 11334 Univ. Calif. Coll. Invert. Pal.

This is very closely allied to *Dendraster ashleyi* (Arnold) because of its wide odd anterior ambulacral petal and great angular divergence of the petals of the bivium, but differs in that the apical system is less eccentric, and in that the test has a more nearly elliptical outline, the transverse diameter being the greater. Its size is usually larger than that of *D. ashleyi*.

Geologic horizon.—Upper Fernando formation, Upper Pliocene.

Locality.—Santa Ynez River district, Santa Barbara County, California, Univ. Calif. loc. 3128 (holotype).

DENDRASTER COALINGAENSIS Twitchell

Plate 28, figures 1*a*, 1*b*, 1*c*

Echinarachnius gibbsii. Arnold, in part, U. S. Geol. Surv. Bull., no. 396, 1909, pp. 34, 42, 162, pl. 28, figs. 4, 4*a*.

(?) *Astrodapsis* sp. indet. Arnold. U. S. Geol. Surv. Bull., no. 396, 1909, p. 30, pl. 28, figs. 5, 5*a*.

Echinarachnius gibbsii. Arnold and R. Anderson, in part, U. S. Geol. Bull., no. 398, 1910, p. 338, pl. 50, figs. 4, 4*a*.

(?) *Astrodapsis,* sp. indet. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 703.

Dendraster coalingaensis Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 196–197, pl. 90, figs. 2*a*–2*c*.

(?) *Sismondia coalingaensis* Twitchell. U. S. Geol. Surv. Mon., vol. 54, 1915, p. 183, pl. 85, figs. 2*a*, 2*b*, 2*c*.

Holotype.—No. 165537 U. S. Nat. Mus.; *figured specimen,* no. 11383 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Average measurements: anteroposterior diameter 32.1 mm., transverse diameter 34.2 mm., greatest height 7 mm. Outline usually subcircular, but in some specimens longitudinally or transversely suboval, the greatest transverse diameter being anterior to the center of the test. Upper surface greatly depressed, especially in the submarginal area; the adult specimens have a relatively greater elevation than the younger ones. Summit situated posterior to the center of the test, but anterior to the apical system. Margin slightly thickened. Apical system quite eccentric to the posterior, the distance from the apical system to the posterior margin in most specimens being equal to about two-fifths of the anteroposterior diameter of the test. Four genital pores are present. Madreporic area comparatively small. Ambulacra wide, being widest at the margin, where they are nearly twice the width of the interambulacra. Petaliferous area relatively long and extending about two-thirds the distance from the apical system to the margin; those of the trivium longer than those of the bivium, with the odd anterior one longer than the anterolateral pair. Angle formed between the petals of the bivium is considerably greater than the angles between the other petals. Lateral petals bent slightly backward. Interporiferous areas of the lateral petals usually somewhat tumid, whereas that of the odd anterior one is nearly flush with the surface of the test. Rows of pores tending to close but little at the extremities of the petals; poriferous areas relatively narrow, each being about one-third the width of the interporiferous area; poriferous areas of the odd anterior petal somewhat narrower than those of the lateral

petals; pores of all petals continue beyond the ends of the petals to the margin. Inferior surface concave to the mouth. Peristome slightly sunken and situated posterior to the center of the test, and approximately opposite the apex of the test. Periproct round, inframarginal, and placed from one to two times its own diameter from the edge of the test, the distance being greater in the larger specimens. Ambulacral furrows branch dichotomously a short distance from the peristome and again near the margin; all pass over the upper surface as lines, which extend toward the apical system. Tubercles prominent, scrobicular, small, and numerous on the interambulacral areas, but on the petaliferous areas they are considerably larger and fewer in number; on the inferior surface the tubercles are large, but near the ambulacral furrows become quite small and very numerous.

Related forms.—*Dendraster coalingaensis* Twitchell is closely related both to *D. gibbsii* (Rémond) and *D. arnoldi* Twitchell. It may be distinguished from the former by having a much less eccentric apical system and smaller angle between the petals of the bivium; the test is relatively thicker, especially at the margin; the petaliferous areas are more tumid; tubercles are larger and not of a uniform size over the surfaces; and the petals of the bivium are longer and narrower; moreover, the lateral petals of *D. gibbsii* are in most specimens flush with the surface of the test, and only in exceptional specimens are they slightly elevated, but in *D. coalingaensis* they are usually elevated. In *D. gibbsii* the upper surface is regularly arched to the summit, whereas in the *D. coalingaensis* the profile is irregular, the test being somewhat flattened in the submarginal area, and usually with a lower apex. *D. arnoldi* Twitchell has some general similarities, yet may be distinguished from *D. coalingaensis* by having a relatively thicker test and margin and a less eccentric apical system. *D. perrini* (Weaver) belongs to the same group as *D. coalingaensis,* but is easily separable on account of its relatively greater thickness; more centrally located apical system, with correspondingly longer petals of the bivium; by its wider petals; in that the posterior margin is usually truncated; and in that the tubercles are of uniform size and comparatively smaller.

Geologic horizon.—Upper Etchegoin formation, Middle Pliocene. Associated with *D. hesperis* Kew and *D. hesperis* var. *gibbosus* Kew.

Localities.—Holotype from "near A. Kreyenhagen's place," Zapata Creek (Twitchell); all occur in the Coalinga district, Fresno County, California; figured specimen from Univ. Calif. loc. 2108.

DENDRASTER DIEGOENSIS Kew, n. sp.

Plate 29, figures 1*a*, 1*b*, 2; plate 30, figures 1, 2*a*, 2*b*

Dendraster excentricus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 223–225, pl. 104, figs. 1*a*, 1*b*, 1*c*, 1*d*.

Holotype.—No. 12257 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of holotype: anteroposterior diameter 77 mm., transverse diameter 82.5 mm., greatest height 9 mm. Marginal outline subcircular, with indistinct shallow notches at the ambitus in the ambulacral areas. Upper surface somewhat flattened in the submarginal area, and then arching within the radius of the petals to the apex which may be moderately low or markedly high; it varies in position from a point slightly anterior to the center of the test to a point coincident with the apical system. Apical system eccentric from one-third to one-sixth the distance of the radius. Madreporic area pentagonal in outline; four large genital pores present in the anterior corners; five small pores in the radial plates at the base of the petals. Petals of the bivium unsymmetrical, shorter but wider than those of the trivium, and tending to close but half the width of the interporiferous area; posterior inner rows of pores form a nearly straight line, whereas the anterior rows are considerably curved; of the outer rows the anterior are more curved. Petals of the trivium of about the same length and breadth; interporiferous area of the lateral pair about two and one-half times the width of each poriferous area. Anterior lateral petals nearly symmetrical, the anterior rows of pores having a curvature slightly greater than the posterior rows. Odd anterior petal symmetrical; poriferous areas extremely narrow, being about one-sixth the width of the interporiferous area; both rows of pores regularly curved, so that the opening at the end of the petal is about one-half the width of the broadest part of the petal. Inferior surface flat. Distinct ambulacral furrows branch dichotomously almost immediately from the peristome and continue to the margin of the test; smaller subsidiary lines are given off which extend over the upper surface for a considerable distance. Peristome rather small, round, and subcentral. Periproct inframarginal and situated about two to three times its own diameter from the margin. Tubercles small, scrobicular, and similar over both surfaces except that they become somewhat larger near the peristome.

Related forms.—This form differs from the Recent *Dendraster excentricus* (Eschscholtz) on account of its narrower poriferous areas and wider interporiferous areas of the petals; in that the anterior

poriferous zones of the paired petals have not so great a curvature; and in that the angle between the petals of the bivium is not so large; averaging about 93°, whereas in the *D. excentricus* it averages 111°.

Geologic horizon.—San Diego, lower San Pedro and Upper Fernando formations, Upper Pliocene; associated with *Dendraster pacificus* Kew.

Localities.—(Holotype), Pacific Beach, San Diego County, California (Calif. Acad. Sci. Coll.); Ventura County, California (Univ. Calif. Coll.); and San Pedro, California (Leland Stanford Jr. Univ. Coll.).

DENDRASTER DIEGOENSIS DIEGOENSIS Kew, n. subsp.

Plate 29, figure 2; plate 30, figures 2*a*, 2*b*

Dendraster excentricus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 223–225, pl. 104, figs. 1*a*, 1*b*, 1*c*, 1*d*.

Holotype.—No. 12257, Univ. Calif. Coll. Invert. Pal.

This form is separated from the other subspecies of this group by having a test which is only moderately elevated and of smaller average size.

Geologic horizon.—San Diego, lower San Pedro, and Upper Fernando formations. Upper Pliocene; associated with *Dendraster pacificus* Kew.

Locality.—Pacific Beach, San Diego County, San Pedro, Los Angeles County, California, and Santa Clara Valley, Ventura County, California.

DENDRASTER DIEGOENSIS VENTURAENSIS Kew, n. subsp.

Plate 29, figures 1*a*, 1*b*; plate 30, figure 1

Dendraster excentricus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 223–225, pl. 105, figs. 1*a*, 1*b*, 1*c*, 1*d*.

Holotype.—No. 11351 Univ. Calif. Coll. Invert. Pal.

This subspecies is characterized by an exceedingly large test. Measurements of specimen no. 11351: anteroposterior diameter 46.5 mm., transverse diameter 104.7 mm., greatest height 7.8 mm.; also by the marked elevation of the abactinal surface within the area limited by the length of the petals, which gives it a humped appearance.

Geologic horizon.—Upper Fernando formation, Upper Pliocene and Pleistocene (?); associated with *Strongylocentrotus franciscanus* A. Agassiz.

Localities.—Holotype from Santa Clara Valley, Ventura County, California; also occurs north of San Fernando Valley, Los Angeles County, California and Las Posas Hills, Ventura County, California.

DENDRASTER EXCENTRICUS (Eschscholtz)

Plate 31, figures 1*a*, 1*b*, 1*c*; plate 32, figures 1, 2

? *Scutella striatula* De Serres. Géognosie terr. du midi de France, 1829, p. 156.

Scutella excentrica Eschscholtz. Zoöl. Atlas, 1831, p. 19, pl. 20, figs. 2, 2*a*, 2*b*.

Echinarachnius excentricus Valenciennes. Voyage Vénus, Zoöph., 1846, pl. 10.

Dendraster excentricus L. Agassiz. Cat. raisonné des échinodermes, Soc. Nat. Ann., 1847, vol. 7, p. 135.

Dendraster excentricus. Gray, Cat. Recent echinoderms, 1855, p. 16.

Dendraster excentricus. Stimpson, Boston Soc. Nat. Hist. Jour., 1857, vol. 6, pp. 526–527.

Scutella striatula. Conrad, U. S. Pacific railroad explorations ——, 1857, vol. 7, pl. 9, figs. 1*a*, 1*b*.

Scutella striatula. Meek, Smithson. Misc. Coll., 1864, vol. 7 (183), p. 2.

Scutella striatula. Gabb, Geol. Surv. Calif., Pal., 1869, vol. 2, p. 110.

Scutella (*Echinarachnius*) *excentricus.* A. Agassiz, Revision of the Echini, Mus. Comp. Zoöl., Ill. Cat., 1872, no. 7, pp. 107, 524–526, pl. 13*a*, figs. 1–4.

Echinarachnius excentricus. Cooper, Catalogue of California fossils, Seventh Rept. Calif. State Mineralogist, 1888, p. 271.

Echinarachnius excentricus. Gregory, Geol. Soc. America Bull., 1891, vol. 3, p. 107.

Echinarachnius excentricus. Merriam, Proc. Calif. Acad. Sci., 1899, ser. 3, Geol., vol. 1, p. 170, pl. 22, fig. 8.

Scutella (*Echinarachnius*) *excentricus.* Arnold, Calif. Acad. Sci. Mem., 1903, vol. 3, p. 91.

Not *Echinarachnius excentricus* Eschscholtz var. Arnold. U. S. Geol. Surv. Bull. no. 322, 1907, pl. 24, fig. 8.

Echinarachnius excentricus. Pack, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 281–282.

Dendraster excentricus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 707.

Dendraster excentricus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 223–225, pl. 104, figs. 1*a*–1*d*, pl. 105, figs. 1*a*–1*d*.

Figured specimens.—Nos. 12163, 12164, and 12165, Univ. Calif. Coll. Invert. Pal.

This form, now living on the Pacific Coast, has been described so often in other works that it seems unnecessary to repeat it here. The figured specimens have been chosen from a large number to illustrate some variations which occur in the petals.

Geologic horizon.—Pleistocene and Recent. A form of this species averaging slightly smaller in size, is also found in the Lower Fernando formation, Lower Pliocene.

Localities.—Recent form from coast of California, Canada, and Alaska. Occurs in San Pedro formation, Pleistocene, near San Pedro, Los Angeles County, California. Pliocene form from Elsmere Canyon, near Newhall, Los Angeles County, California.

DENDRASTER GIBBSII (Rémond)

Plate 25, figures 2*a*, 2*b*, 2*c*

Scutella gibbsii Rémond. Proc. Calif. Acad. Sci., vol. 3, 1863–67, pp. 13, 14.

Scutella gibbsii. Meek, Smithson. Misc. Coll., vol, 7, no. 183, p. 2, 1864.

Scutella gibbsii. Gabb, Geol. Surv. Calif., Pal., vol. 2, 1869, pp. 37, 109, pl. 13, figs. 66, 66*a*.

Scutella gibbsii. Cooper, Cat. Calif. Fossils, Seventh Rept. State Mineralogist, 1888, p. 271.

Echinarachnius gibbsi Merriam, Proc. Cal. Acad. Sci., ser. 3, Geol., vol. 1, 1899, p. 169, pl. 22, fig. 7.

Scutella gibbsi. F. M. Anderson, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 2, 1905, p. 180 (listed).

Echinarachnius gibbsii. Pack, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 282–283.

Echinarachnius gibbsii. In part, Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, pl. 13, figs. 1, 2; pl. 19, figs. 1, 2; pl. 20, fig. 7.

Echinarachnius gibbsii. In part, Arnold and Anderson, U. S. Geol. Surv. Bull., no. 398, 1910, pl. 35, figs. 1, 2; pl. 41, figs. 1, 2; pl. 42, fig. 7

Dendraster gibbsi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 704.

Dendraster gibbsii. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 193–195, pl. 89, figs. 1*a*, 1*b*, 2, 3, 4; pl. 108, fig. B.

Dendraster gibbsii. Nomland, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, 1916, p. 81; *ibid.*, p. 202 (listed).

Holotype.—No. 11050 Univ. Calif. Coll. Invert. Pal.; *figured specimens*, 11021 and 11380 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen no. 11021 Univ. Calif. Coll. Invert. Pal.: anteroposterior diameter 49.2 mm., transverse diameter 45.0 mm., greatest height 10.3 mm. Outline suboblong to subquadrate, often suboval to subcircular. The shape is quite variable and the greatest diameter may be either in the transverse or antero-

posterior direction; greatest width usually posterior to the center, but in front of the apical system. Upper surface depressed but arching regularly to the summit, which is eccentric posteriorly and anterior to the apical system. Apical system situated far back, toward the posterior edge of the test, the distance from the center of the test to apical system averaging about two-fifths the distance from the center to the posterior edge. Margin rounded; usually possessing a notch in the posterior interambulacral area, which continues, in most specimens, as a shallow depression on the upper surface toward the apical system. Madreporic body large and subpentagonal in outline; produced posteriorly into the interambulacral area, forming a small lobe; four large genital pores at the anterior corners of the madreporite, the two anterior ones being closer together than the posterior; five perforated radial plates, situated at the base of the petals. Interambulacra wider than the ambulacra at the margin; dorsal portions of the ambulacra petaloid. Petals moderately broad, wide open at their extremities, and reaching a point that is slightly over three-fourths the distance to the margin; usually flush with the test, but the lateral petals may be somewhat raised. Lateral petals unsymmetrical; those of the bivium about one-half the length of the trivium, though of the same width; inner rows of rounded pores diverge at first and then converge slightly; pores conjugated; outer rows of elongate pores diverge to a greater degree and then converge close to the inner rows at the extremity of the petal; in the anterior paired petals the convergence of the inner rows is less; the convergence of the anterior rows of pores in both sets of petals greater than in the posterior rows; odd anterior petal symmetrical and elliptical in outline. Poriferous areas of the paired petals of the same width, each being equal to about one-half the width of the interporiferous area; poriferous area of the odd anterior petal narrower and with a correspondingly wider interporiferous area. Average angle between the petals of the bivium 124 degrees. Inferior surface flat or very slightly concave. Peristome small, irregular in outline, and posteriorly eccentric, though to a less degree than the apical system, and corresponding closely with the eccentricity of the apex. Ambulacral furrows well marked; dichtomously branched near the peristome, which in turn send off numerous branches that continue over the upper surface for a short distance; odd anterior ambulacral furrows are less developed than the others; main branches send off

many irregular lines on their way to the margin. Periproct inframarginal, circular or subcircular, and situated about one or two millimeters from the margin. Surface covered by numerous small tubercles situated in poorly developed scrobicules; uniform in size except near the peristome, where they are larger. Structure of interior of test as in *Dendraster excentricus* (Eschscholtz), except that the radial partitions do not extend so far in toward the center of the test.

Related forms.—*Dendraster gibbsii* may be separated from *D. excentricus* by its thicker test, more eccentric apical system, and by its usually more widely divergent petals. From *D. hesperis* Kew it differs in having the apical system more eccentric as well as the apex, the angle between the posterior lateral petals is much greater, petals extend nearer the margin with the bivium longer than the trivium, the periproct is closer to the margin, and the peristome is more posteriorly eccentric. It is closely related to *D. ashleyi* (Arnold), but differs in its less eccentric apical system, less widely divergent posterior petals, and thicker test.

Geologic horizon.—Lower Etchegoin (Jacalitos) and Upper Etchegoin formations of the Pliocene. Associated with *Astrodapsis arnoldi peltoides* (Anderson and Martin) in the Lower Etchegoin formation.

Localities.—Holotype from "oil region of Tulare Lake," south of Coalinga, Fresno County, California. Figured specimens from Coalinga district.

DENDRASTER GIBBSII HUMILIS Kew, n. var.

Plate 25, figures 3*a*, 3*b*

Echinarachnius excentricus var. Arnold. U. S. Geol. Surv. Bull., no. 322, 1907, pl. 24, fig. 8.

Holotype.—No. 11379 Univ. Calif. Coll. Invert. Pal.

This seems to be an intermediate form between *Dendraster gibbsii* (Rémond) and *D. ashleyi* (Arnold), differing from the former in having a thinner test with angulated margins; from the latter it differs in that the odd anterior petal is narrower, about the same width as the anterior lateral pair, and in that the apical system is less eccentric.

Geologic horizon.—Upper Etchegoin and Upper Fernando formations, Upper Pliocene; may be associated with *Dendraster ashleyi.*

Localities.—Coalinga district, Fresno County, California, Univ. Calif. loc. 2100 (holotype), and Santa Maria district, California.

DENDRASTER HESPERIS Kew, n. sp.

Plate 26, figures 1*a*, 1*b*, 1*c*

Holotype.—No. 11381 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of holotype: anteroposterior diameter 47.5 mm., transverse diameter 51.4 mm., greatest height 12.0 mm. Marginal outline subcircular, the greatest diameter being either in an anteroposterior or transverse direction; greatest transverse diameter immediately posterior to the center of the test. Upper surface depressed and arching regularly to the summit, the latter being slightly eccentric to the posterior. Margin rounded and of moderate thickness; truncated in the posterior interambulacral area and indented by a broad notch, which continues toward the apical system as a wide, shallow depression on the upper surface. Apical system eccentric to the posterior, being situated about one-fourth the radius of the test from the center. Madreporite large and pentagonal; four genital pores present, with the two anterior ones closer together than the posterior pair; perforated radial plates are placed at the base of each petal. Ambulacra wide at the ambitus, where they are broader than the interambulacra. Dorsal portions petaloid. Petals slightly elevated, moderately broad, and open at their extremities; those of the bivium about two-thirds the length and slightly wider than those of the trivium; inner rows of pores of the paired petals diverge and then slightly converge at their ends; outer rows diverge to a slightly greater degree and then converge so as to meet the inner rows at the extremity of the petal; anterior rows of pores curve slightly more than the posterior rows, giving the petal the appearance of being bent backward. Odd anterior petal symmetrical, the rows of pores diverging and then converging slightly to the end. A few pores continue beyond to the margin in all the petals. Poriferous areas of the petals of the bivium widest, each being about one-half the width of the interporiferous area; that of the anterior paired petal about one-third, and that of the odd anterior one about one-fourth the width of the interporiferous area. Under surface slightly concave, deepening toward the center. Peristome large, situated slightly posterior to the center of the test. Periproct of medium size, inframarginal, and distant from the margin the length of its own diameter or more. Tubercles relatively prominent and irregularly distributed over the test; mamelons are present, which project above rather wide scrobicules. Ambulacral furrows are well marked, divide

dichotomously a short distance from the peristome, branch again two-thirds the distance from the mouth to the margin, and continue on the upper surface as faint lines.

Related forms.—In general appearance this species resembles *Dendraster gibbsii* (Rémond), but has been separated from it on account of its less eccentric apical system, longer petals of the bivium, smaller angle between the petals of the bivium, and in that the petals are usually broader. From the variety *D. hesperis* var. *gibbosus* Kew it differs in lacking the great transverse breadth of test and the extreme elevation of the summit, or abactinal hump. It may easily be separated from *D. arnoldi* Twitchell and *D. coalingaensis* Twitchell on account of its smaller sized tubercles, which are of the same size over the test, whereas in the latter two forms the tubercles are larger on the interporiferous areas of the petals.

Geologic horizon.—Pecten coalingaensis zone of the Upper Etchegoin formation, Upper Pliocene. Occurs associated with *Dendraster gibbsii* (Rémond) and *D. hesperis* var. *gibbosus* Kew.

Localities.—Coalinga district, Fresno County, California; holotype from Univ. Calif. loc. 3004.

DENDRASTER HESPERIS GIBBOSUS Kew, n. var.

Plate 26, figures 2*a*, 2*b*

Holotype.—No. 11022 Univ. Calif. Coll. Invert. Pal.

This form differs from *Dendraster hesperis* Kew in having the transverse diameter considerably greater than the anteroposterior diameter; and in that it possesses a prominently elevated abactinal surface, which gives the test a humped appearance; also the rows of pores tend to converge more in the distal ends of the petals.

Geologic horizon.—Upper Etchegoin formation, Upper Pliocene; associated with *Dendraster hesperis* Kew.

Localities.—Holotype from Coalinga district, Fresno County, California, Univ. Calif. loc. 525; all other specimens from the same region.

DENDRASTER JACALITOSENSIS Kew, n. sp.

Plate 25, figures 1*a*, 1*b*

Holotype.—No. 11034 Univ. Calif. Coll. Invert. Pal.

Size large. Measurements of holotype: anteroposterior diameter 61.4 mm., transverse diameter 63.7 mm., greatest height 10.5 mm. Test depressed, and noticeably thin at the margin; outline subpen-

tagonal, with transverse diameter about the same length as the antero-posterior diameter; ambitus broadly but distinctly notched in the posterior ambulacral areas. Apex rather high, and slightly eccentric to the posterior; the greatest elevation of the test is within the area limited by the length of the petals. Apical system situated immediately back of the apex and center of test. Madreporic body comparatively small; a genital pore in each corner of the madreporite, except the odd posterior one; the anterior pair closer together than the posterior pair. Dorsal portions of the ambulacra petaloid. Petals subelliptical in outline; rows of pores in all petals converge slightly near their extremities; petals unequal in length, those of the trivium longer than the bivium, with the odd anterior one longest; those of the bivium reach a little over one-half the distance to the margin, whereas those of the trivium extend about two-thirds the distance; poriferous areas narrow in comparison with the width of the petal, each being about one-third the width of the interporiferous area except in the odd anterior petal, where the poriferous area is about one-fourth the width; lateral petals have the poriferous areas slightly depressed; pores conjugate and oval in shape. Inferior surface very slightly concave near the peristome. Peristome small and situated but a short distance posterior to the center, being approximately opposite the apex of the test. Ambulacral furrows well marked, dichotomously divided a short distance from the peristome, which in turn branch again before reaching the margin. Periproct small, round, inframarginal, and situated a distance about equal to its own diameter from the edge of the test. Both surfaces covered by numerous small tubercles of uniform size.

Related forms.—This species most closely resembles *Dendraster diegoensis diegoensis* Kew, though differing in that the apical system is slightly less eccentric; that the peristome is more nearly central; and in that the poriferous areas of the petals are relatively narrower with a complementary broader interporiferous area. In the shape of its odd anterior petal it seems to be closely allied to *D. ashleyi* (Arnold), but is easily separated on account of its less eccentric apical system. From *D. gibbsii* (Rémond) it differs in its thicker test, and from *D. gibbsii* var. *humilis* Kew in having also a wider odd anterior petal.

Geologic horizon.—Upper Etchegoin formation, Upper Pliocene; associated with *Dendraster gibbsii* var. *humilis* Kew.

Locality.—Holotype from Coalinga district, Fresno County, California, Univ. Calif. loc. 2954.

DENDRASTER PACIFICUS Kew, n. sp.

Plate 33, figures 1*a*, 1*b*, 1*c*

Cotypes.—No. 448 Calif. Acad. Sci. Coll. Pal. and no. 11340 Univ. Calif. Coll. Invert Pal.

Test small. Average measurements of holotype: anteroposterior diameter 36 mm., transverse diameter 35 mm., greatest height 8.3 mm. Outline subpentagonal. Upper surface depressed, and rising gently from a moderately thickened and rounded margin to a low apex situated slightly anterior to the center of the test. Very indistinct depressions are present in the interambulacral areas. Apical system slightly eccentric to the posterior. Petals of the trivium of the same length and longer than those of the bivium, extending a little over half the distance from the apical system to the margin. Rows of pores diverge for about one-half the length of the petal and then continue in parallel lines to the end, the outer rows converging but little in the distal portion of the petal; a few sporadic pores extend beyond nearly to the edge of the test. Odd anterior petal is slightly narrower than the lateral petals. Petals are more or less elevated, this being a distinctive character. Four large genital pores and five perforated radial plates are present in the apical system. Lower surface concave to the peristome; the latter is subcircular in outline and posterior to the center of the test, being opposite the apical system. Distinct, broad ambulacral furrows present, branching dichotomously a short distance from the mouth and continuing to the margin. Tuberculation prominent; consists of a few large scrobicular tubercles on the petals; smaller secondary tubercles are present over the remainder of the upper surface, interspaced with numerous milliaries; the under side is covered by a few large tubercles of the same size as on the petals, and interspaced with numerous smaller ones. Periproct round, inframarginal, and situated a distance about equal to its own diameter from the edge of the test.

Related forms.—This form seems to be closely related to *Dendraster arnoldi* Twitchell, but differs in that it has a less eccentric apical system; has shallow interambulacral grooves on the upper surface; and possesses a distinctly pentagonal outline. It may be distinguished from other west coast dendrasters on account of its large tubercles, very slightly eccentric apical system, and a swollen margin. From *D.*

coalingaensis Twitchell, which it resembles very closely, it differs in having a less eccentric apical system and small interambulacral grooves.

Geologic horizon.—San Diego formation, Upper Pliocene.

Localities.—Cedros Island, Lower California; Pacific Beach, San Diego County, California.

DENDRASTER PERRINI (Weaver)

Plate 28, figures *3a, 3b, 3c*

Scutella perrini Weaver. Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, 1908, p. 273, pl. 22, fig. 2.

Scutella perrini. Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, pp. 30, 34, 38, 162, pl. 28, figs. 1, 2.

Scutella perrini Arnold, U. S. Geol. Surv., Geol. Atlas, Santa Cruz folio (no. 163), p. 6.

Astrodapsis perrini. Rathbun, Proc. U. S. Nat. Mus., vol. 35, 1908, p. 342. Listed on authority of R. Arnold and erroneously ascribed to Merriam.

Echinodiscus (?) perrini. Lambert, Rev. crit. paléozoölogie, vol. 13, 1909, p. 122.

Scutella perrini. Arnold and Anderson, U. S. Geol. Surv. Bull., no. 398, 1910, p. 338, pl. 50, figs. 1, 2.

Merriamaster perrini. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 704.

Merriamaster perrini. Lambert, Rev. crit. paléozoölogie, vol. 15, 1911. p. 64.

Dendraster perrini. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 190–191, pl. 88, figs. 2, *3a, 3b, 3c.*

Holotype.—Specimen in Leland Stanford Jr. Univ. Dept. Geol.; *figured specimen,* no. 11018 Univ. Calif. Coll. Invert Pal.

Test rather small. Measurements of specimen no. 11018 Univ. Calif. Coll. Invert. Pal.: anteroposterior diameter 43.8 mm., transverse diameter 44.4 mm., greatest height 11.5 mm. Marginal outline subcircular to longitudinally suboval, with very faint notches in the ambitus at the ambulacral areas; margin unusually thick, with the upper surface greatly depressed but regularly arching to the summit, which is subcentral. Apical system is posteriorly eccentric, being about one-fifth to one-sixth the distance from the center to the margin. Ambulacra wider than the interambulacra at the ambitus. Petals large, broadly subelliptical in outline, of unequal size, and having a slight tendency to be elevated in all except in very young specimens; wide open at their extremities, and extending nearly to the margin. Posterior pair of petals less divergent than the anterior pair; ends

of both pairs of lateral petals bent slightly backward as in other related forms. Poriferous zones moderately wide; interporiferous areas broad, being about three or four times the width of the poriferous areas. Pores oval and conjugated. Actinal surface faintly concave. Indistinct, broad ambulacral furrows extend from the mouth to near the margin; poorly developed broad lines branch off from the main furrows less than half way to the edge. Both surfaces are covered by numerous prominent perforated tubercles which are surrounded by wide granular scrobicules; the tubercles are regularly spaced and of the same size, except those situated on the poriferous zones and those close to the apical system, which are smaller. Spines slender, covered with granules, arranged in longitudinal rows; these have a heavy base to fit the large mamelon of the tubercle. Peristome small, subcircular, posteriorly eccentric, and situated opposite the apical system. Periproct circular and inframarginal to almost marginal.

Related forms.—*Dendraster perrini* is very closely related to *D. coalingaensis* Twitchell and *D. arnoldi* Twitchell, from which it differs mainly in having a much thicker test and tubercles which are of uniform size over the surface.

Geologic horizon.—Upper Etchegoin and Purisima formations, Upper Pliocene. Associated with *Dendraster gibbsii* var. *humilis* Kew and *D. arnoldi* Twitchell.

Localities.—Holotype from near Coalinga, California (Weaver); figured specimen no. 11018 from Coalinga district, Fresno County, California; Zapato Creek, one-half mile south of A. Kreyenhagen's place Coalinga district, California (U. S. Geol. Surv.); also reported from San Gregorio, California.

CALASTER Kew, n. subgenus

Dendraster. In part, Clark and Twitchell, Mesozoic and Cenozoic Echinodermata of the United States, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 190.

The subgenus *Calaster* is used here to include all dendraster-like forms having a distinctly supramarginal periproct.

DENDRASTER (CALASTER) INTERLINEATUS (Stimpson)

Plate 35, figures 1*a*, 1*b*

Scutella interlineata Stimpson. Pac. R. R. Rept., vol. 5, 1856, pp. 153, 154, pl. 4, fig. 30.
Scutella interlineata. Rémond, Proc. Calif. Acad. Sci., vol. 3, 1863–67, pp. 14, 15.
Scutella interlineata. (Blake) Meek, Smithson. Misc. Coll., vol. 7, 1864, no. 183, p. 2.
Scutella interlineata. Gabb, Geol. Surv. Calif., Pal., vol. 2, 1869, p. 110.
Scutella interlineata. Cooper, Cat. Calif. Fossils, Seventh Rept. Calif. State Mineralogist, 1888, p. 271.
Scutella interlineata. Merriam, Univ. Calif. Bull. Dept. Geol., vol. 2, 1898, pp. 110, 111, 113, 117 (mentioned in text).
Not *Scutella interlineata.* Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, 1899, pp. 168–169, pl. 22, fig. 6.
Dendraster (?) interlineatus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 706.
Not *Dendraster interlineatus.* Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 216–217, pl. 100, figs. 2*a*, 2*b*.

Neotype.—No. 11353 Univ. Calif. Coll. Invert. Pal.

Size of test very large. Measurements of specimen no. 11353: anteroposterior diameter 99.5 mm., transverse diameter 97.7 mm., greatest height 12.8 mm. Marginal outline subcircular; upper surface greatly depressed and regularly arched to the summit, which is anterior to the apical system. Apical system slightly eccentric to the posterior. Apical star symmetrical. Ambulacral areas broaden rapidly from the ends of the petals to the edge of the test, being wider here than the interambulacra; dorsal portions of the ambulacra petaloid. Petals symmetrical, large, and elliptical in outline; extend slightly more than three-fourths the distance from the apical system to the margin. Rows of pores of lateral petals almost closing at their extremities; poriferous areas wide, each being nearly as broad as the interporiferous area; the interporiferous area of the petals of the bivium usually slightly narrower than that in the anterior lateral ones. Odd anterior petal different, being wide open at its extremity, slightly broader, and with narrower poriferous areas and wider interporiferous area. Poriferous areas of all the petals usually somewhat depressed below the surface of the test; pores conjugate. Inferior surface flat, having well marked ambulacral furrows consisting of straight, deep grooves, which continue from the peristome to the margin, with less distinct branches near the peristome. Peristome central. Periproct small, round, and supramarginal, being placed

the width of a marginal plate from the edge of the test. Tubercles small and of uniform size on both sides of the test, except near the peristome, where they become slightly larger and less crowded. The spines on the upper surface are often visible, and are about one millimeter in length, longitudinally striated, and club-shaped, the distal end being twice the size of the proximal end; those on the under surface are two to three millimeters in length, also longitudinally striated, but tapering to the end.

Related forms.—This species most closely resembles *Calaster oregonensis* (Clark), but several constant differences exist which permit *C. interlineatus* to be readily distinguished. The main differences are: *C. interlineatus* has a less eccentric apical system which is constant, has a more nearly circular outline, attains a greater size, and has petals more nearly elliptical and symmetrical in shape, and nearly equal in length. From *Scutella fairbanksi* Arnold and *S. gabbi* (Rémond) it may easily be distinguished by its greater size, slightly posteriorly eccentric apical system, and in that the periproct is situated farther from the margin on the upper surface.

Discussion.—This form is without doubt the same as the poorly preserved form Stimpson originally described. The type was not available, but his illustration coincides in all respects with the specimens in the collection of the University of California. In the writer's opinion the specimens figured by Merriam and Twitchell do not fit the original description. Stimpson's figure shows the similar symmetrical petals, the slightly eccentric apical system, and large size, all of which are distinctive for *Calaster interlineatus.*

Geologic horizon.—Lower Merced series, Upper Pliocene; in horizon above that in which *Calaster oregonensis* var. *major* Kew is found.

Locality.—Stimpson's holotype from south of Point Lobos, near San Francisco, California; neotype, specimen no. 11353, from seacliffs north of Mussel Rock on west side of San Francisco Peninsula, San Mateo County, California. Univ. Calif. loc. 1726.

DENDRASTER (CALASTER) OREGONENSIS (W. B. Clark)

Plate 33, figures *2a, 2b*

Scutella (Echinarachnius) oregonensis W. B. Clark in Dall, U. S. Geol. Surv. Prof. Paper, no. 59, 1909, p. 140, pl. 7, fig. 2.

Dendraster oregonensis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 195, pl. 90, fig. 1.

Holotype.—No. 153975 U. S. Nat. Mus. *Figured specimens,* nos. 449 and 450 Calif. Acad. Sci. Coll. Pal.

Test small. Measurements of specimen no. 449: anteroposterior diameter 25.4 mm., transverse diameter 26.5 mm., greatest height 2.3 mm. Outline subpentagonal to subcircular. Upper surface considerably depressed and arching to the summit, which is slightly anterior to the apical system; submarginal area somewhat flattened; margin thin. Apical system distinctly eccentric to the posterior. The ambulacra wider than the interambulacra at the ambitus, the plates of the former becoming greatly enlarged beyond the extremities of the petals. Dorsal portions of the ambulacra petaloid. Petals large, subelliptical in shape, asymmetric, and extending about four-fifths the distance to the margin; petals of the bivium shorter than the lateral petals of the trivium, with the odd anterior one longer than the others. Rows of pores of the lateral petals nearly closing at their extremities; posterior inner rows in bivium and anterolateral pair nearly straight; anterior rows much curved. Poriferous area of the bivium wide, each being of about the same width as the interporiferous area; that of the lateral petals of the trivium not so wide, each being slightly more than half the width of the interporiferous area. Odd anterior petal wider than the others; poriferous area quite narrow, with a correspondingly large interporiferous area, and the rows of pores not converging so closely at their ends as in the other petals. A few pores continue beyond the extremities of the petals. Inferior surface flat except near the peristome, where it becomes faintly concave. Ambulacral furrows well marked, branching about one-third the distance from the peristome to the margin, with the latter again branching near the edge of the test; the main furrows die out when about two-thirds the distance to the margin. Peristome slightly eccentric posteriorly, round in outline, and of moderate size. Periproct supramarginal, and situated from the edge of the test a distance equal to the width of a marginal plate. Tubercles small, crowded, of the same size on the upper surface and near the margin on the under surface, but become larger, more noticeably scrobiculate, and less crowded toward the peristome. The internal skeleton consists of radiating partitions in the interambulacral areas, which connect with the upper surface near the margin, and from that place to the peristome extend as thick ridges on the floor; between these are intercommunicating pillars and irregularities on the lower surface. The auricles are well developed.

Related forms.—This form is most closely related to *Calaster interlineatus* (Stimpson), but may be distinguished by its more eccentric apical system; the smaller size of the test; the subpentagonal to subelliptical outline; and petals which are less symmetrical in shape. From the true California dendrasters it is easily separated by its supramarginal periproct, and from the scutellid forms by the posterior eccentricity of the apical system.

Geologic horizon.—Lower Merced series, Upper Pliocene; occurring stratigraphically below *Calaster interlineatus;* also in the Empire, Elk River, and Purisima formations, Upper Pliocene. Associated in the Purisima formation with *D. perrini* (Weaver) and *D. gibbsii* var. *humilis* Kew.

Locality.—Holotype from "Upper Miocene sandstones at Fossil Point, Coos Bay, Oregon" (Dall); figured specimens also from this locality.

DENDRASTER (CALASTER) OREGONENSIS GIBBOSUS Kew, n. var.

Plate 33, figures *3a, 3b, 3c*

Cotypes.—Nos. 11385 and 11386 Univ. Calif. Coll. Invert. Pal.

This form differs from *Calaster oregonensis* (Clark) in that its upper surface is markedly elevated; the degree of slope is less in the submarginal area, which gives the abactinal surface a distinctly humped appearance.

Geologic horizon.—Upper Wildcat formation, Upper Pliocene.

Locality.—Cotypes from near Shively, Humboldt County, California, Univ. Calif. loc. 1881.

DENDRASTER (CALASTER) OREGONENSIS MAJOR Kew, n. var.

Plate 34, figures *1a, 1b, 1c*

Scutella interlineata. Merriam, Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, no. 5, 1899, pp. 168–169, pl. 22, fig. 6.

Dendraster (?) *interlineatus.* Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 706.

Dendraster interlineatus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 216–217, pl. 100, figs. *2a–2b*.

Cotypes.—Nos. 11044 and 11352 Univ. Calif. Coll. Invert. Pal.

This form differs from the typical *Dendraster* (*Calaster*) *oregonensis* only in its much greater size. Measurements of specimen no. 11352: anteroposterior diameter 73.3 mm., transverse diameter 76.3 mm., greatest thickness 9 mm.

Geologic horizon.—Lower Merced formation, Wildcat series, and Purisima formation. Upper Pliocene.

Localities.—Cotypes from Eel River, Humboldt County, California. Univ. Calif. locs. 71 and 1876.

Genus SCUTASTER Pack

SCUTASTER ANDERSONI Pack

Plate 26, figures 3*a*, 3*b*

Scutaster andersoni Pack. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, pp. 278–279, pl. 23.

Scutaster andersoni Pack. *Ibid.*, vol. 7, 1913, pp. 301–302, pl. 15, figs. 2*a*, 2*b*.

Scutaster andersoni. Stefanini, Boll. Soc. geol. ital., vol. 30, p. 704.

Scutaster andersoni. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 206, pl. 93, fig. 1.

Holotype.—No. 11029 Univ. Calif. Coll. Invert. Pal.; *lectotype*, in U. S. Nat. Mus.

Pack's original description is as follows:

Dimensions.—Diameter through the anterior petal 53 mm.; diameter between the lateral margins 62 mm., height 5 to 6 mm.

Test subcircular in outline, edges markedly thin. Upper surface regularly arched from the margin; apex anterior to the center. Apical system small and apparently central. Ambulacral star small; petals extending slightly less than half way to the margin of the test, closed at the ends. Lateral petals broader than the posterior ones, but of almost the same length. Poriferous zones broad, and continuing full width almost to the ends of the petals. In the posterior petals the interporiferous area forms about one-third the width of the petal. Poriferous zones of the lateral petals equal in width to those of the posterior petals, but enclosed area broader. In the extension of the three anterior petals are broad lunules, over half as long as the petals; shallow grooves extend from the lunules to the margin. Anterior lunule slightly farther from the apical system than are the lateral ones. From the ends of the posterior petals the plates enlarge, and the area broadens rapidly. No lunules were seen here, nor in the posterior interambulacral space. They may be represented by marginal notches, as the posterior edge of the specimen is lacking.

In the later description he says:

The new material shows that the test is subcircular to oval in outline. The apical system is slightly posterior to the middle of the test; the ratio of the distance from the apical system to the posterior and anterior margins in the figured specimen is as 23:30. The middle of the arch of the abactinal surface is slightly anterior to the middle of the test, being located approximately in the middle of the anterior petal. In the figured specimen the distance from the middle of the arch to the anterior margin is 21 mm., to the posterior margin 32 mm. The posterior ambulacra terminate rather abruptly, the edge of the test forming broad, shallow notches which fashion the posterior interambulacral area into a process somewhat similar to that of *Scutella norrisi.* The test is much compressed. In some cases there is a slight tendency for the arch of the

abactinal surface to flatten near the lateral margins, but in most cases the profile of the upper surface is regular between these margins. The slope of the abactinal surface from the apex to the anterior margin is rounded and rather abrupt, to the posterior margin flat and gentle. There are neither lunules nor narrow marginal notches in the posterior half of the test. The petals are almost closed, the outer row of pores swinging in abruptly toward the inner row. The posterior petals are slightly shorter as well as slightly narrower than the lateral ones. Isolated pores are visible for only one or two plates beyond the outer end of the petals. The greatest width of the test is posterior to the center, and approximately through the apical system.

Geologic horizon.—Uppermost Oligocene.

Localities.—Holotype from near Muir, Contra Costa County, California, Univ. Calif. loc. 424. Figured specimen from north slope of San Emigdio Mountains at southern end of San Joaquin Valley, Kern County, California; occurs abundantly at this location.

Genus ENCOPE L. Agassiz

ENCOPE TENUIS Kew

Plate 36, figure 1; plate 37, figures 1*a*, 1*b*

Encope tenuis Kew. Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1913, pp. 47–48, pl. 1, fig. 1; pl. 2, fig. 1.

Encope tenuis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 111, 208.

Cotypes.—Nos. 10050 and 10051 Univ. Calif. Coll. Invert. Pal.

Size large. Average measurements: anteroposterior diameter 102.5 mm., transverse diameter 100.5 mm., greatest thickness 11.5 mm. Test broad, transverse diameter sometimes greater than the anteroposterior diameter. Greatest width posterior to the center. Outline irregularly subcircular. Test thin, with sharply angular margin. Summit posterior to apical system, and immediately anterior to interambulacral lunule or foramen. Area immediately surrounding the lunule somewhat tumid. Ambulacral notches broad, deep, contracting slightly near the margin of the test and tending to close. Both interambulacral lunule and ambulacral notches varying somewhat in size. Apical system central. Petals rather narrow, nearly closed, and reaching about two-thirds the distance to the margin. The two lateral petals of the trivium broader, and averaging nine per cent shorter than the others. Interporiferous areas somewhat lenticular, and at widest part about two-thirds the width of each poriferous area. Actinal side flat; marked by deep ambulacral furrows, which branch immediately from the peristome and a second time a short distance from the outer

margin. The main furrows are broad, shallow, and straight, deepening as the ambulacral notches are approached. Mouth small and not sunken. Anus situated on the inferior surface slightly anterior to the interambulacral lunule.

Related forms.—This species closely resembles the Recent *Encope californica* Verrill. The latter differs in its thicker margin and usually closed ambulacral notches.

Geologic horizon.—Lower division of the Carrizo Creek beds, Pliocene.

Locality.—Coyote Mountain, Imperial County, California. Cotypes from Univ. Calif. loc. 2064.

Genus MELLITA Agassiz

MELLITA LONGIFISSA Michelin

Plate 38, figures 1*a*, 1*b*, 1*c*, 1*d*, 1*e*

Mellita longifissa Michelin, Rev. Mag. Zoöl., no. 8, 1858.

Mellita longifissa. A. Agassiz, Revision of the Echini, Mus. Comp. Zoöl., Ill. Cat., no. 7, pt. 1, 1872–74, p. 535, pl. 11, figs. 24–27.

Figured specimen.—No. 11025 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen no. 11025: antero-posterior diameter 70 mm., transverse diameter 75.5 mm., greatest height 10 mm. Outline broadly subovate; rounded posteriorly, with a faint, broad marginal notch in the odd posterior interambulacral area; greatest width posterior to the center of the test. Margin very thin, slightly thicker in front. Apex anteriorly eccentric; upper surface sloping with an even profile to the rear, and to the anterior margin with a more or less rounded one. Lunules narrow and slit-like; odd posterior one the longest, the two anterior the shortest. Apical system anteriorly eccentric to a slight degree, and behind the summit. Madreporic area large; four genital pores and five small perforated radial plates. Petals unequal in length; posterior pair the longest and slightly curved backward; anterior lateral pair considerably shorter, with the odd one slightly shorter than the posterior lateral pair. Poriferous areas wide, each zone being broader than the interporiferous area, with the exception of the odd anterior petal, in which the interporiferous area is wider than each poriferous zone. Inner rows of pores extend in approximately parallel lines to the

end of the petals. Inferior surface flat. Ambulacral furrows well marked; divide close to the peristome with the exception of the odd anterior one, which bifurcates when about one-fourth the distance from the peristome to the margin; short branches are sent out toward the lunules and longer ones are given off close to the margin. Peristome round and situated anterior to the center of the test. Periproct situated about twice its own diameter posterior to the peristome, but still slightly anterior to the center of the test. Tubercles on the upper surface very small, scrobicular, and crowded; those of the under side larger and irregularly spaced, being absent between the main branches of the ambulacral furrows but present in the median furrow.

Geologic horizon.—Upper San Pedro formation, Pleistocene.

Locality.—Newport Beach, Orange County, California.

Suborder SPATANGINA Jackson

Tribe CASSIDULOIDEA Duncan

Family CASSIDULIDAE Agassiz

Genus CASSIDULUS Lamarck

Subgenus RHYNCHOPYGUS d'Orbigny

CASSIDULUS (RHYNCHOPYGUS) CALIFORNICUS (F. M. Anderson)

Plate 39, figures 1*a*, 1*b*, 1*c*, 1*d*

Cassidulus californicus F. M. Anderson. Proc. Acad. Sci., ser. 3, Geol., vol. 2, 1905, p. 194, pl. 13, figs. 6–7.

Cassidulus californicus. Arnold, U. S. Geol. Surv. Bull., no. 396, 1909, pp. 13, 112, pl. 4, figs. 1, 1*a*.

Cassidulus californicus. Arnold and R. Anderson, *ibid.*, Bull., no. 398, 1910, pp. 70, 284, pl. 26, figs. 1, 1*a*.

Cassidulus californicus. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 696.

Cassidulus californicus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 140, pl. 65, figs. 2*a*–2*b*.

Holotype.—Calif. Acad. Sci. Coll. (destroyed in San Francisco fire); *neotype*, specimen no. 11348 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of specimen no. 11348: anteroposterior diameter 18.2 mm., transverse diameter 14.5 mm., greatest height 8.2 mm. Ambital outline subelliptical; slightly broader behind than in front. Upper surface regularly rounded from a thickened margin to

a rather high central apex; posterior end somewhat truncated. Apical system small and eccentric to the anterior; four large genital pores present. Ambulacra narrow and subpetaloid. Petals of the bivium considerably longer than those of the trivium; all very narrow and of the same width; rows of pores of the paired petals extend in approximately parallel lines the entire length of the petals, so that the latter are wide open at their extremities; odd anterior petal slightly elliptical in outline, the rows of pores converging to a slight degree in the distal part. Inferior surface concave around the mouth, which is pentagonal in outline and transversely elongate. Periproct large, transversely elongate, situated above the ambitus and below a prominent overhanging rostrum. Rather large scrobicular tubercles covering the under side; those of the upper surface considerably smaller.

Related forms.—This form may be separated from other Pacific Coast species of *Rhynchopygus* by its very narrow petals, which have approximately parallel rows of pores.

Geologic horizon.—Tejon series, Upper Eocene; associated with *Scutella* (?) sp. Anderson.

Locality.—Original holotype from "Avenal Sands west and north of Coalinga;" neotype from SW. ¼ of NW. ¼, Sec. 24, T. 18 S., R. 14 E., near Salt Creek, Coalinga district, Fresno County, California.

CASSIDULUS (RHYNCHOPYGUS) ELLIPTICUS Kew, n. sp.

Plate 39, figures *3a, 3b, 3c, 3d*

Cotypes.—Nos. 11346 and 11347 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of specimen no. 11346: anteroposterior diameter 20.2 mm., transverse diameter 13.6 mm., greatest height 6.3 mm. Ambital outline strongly elliptical. Upper surface somewhat depressed and rising immediately from the margin to the apex, which is anteriorly eccentric. Apical system small and eccentric to the anterior; four relatively large genital pores present. Ambulacra narrow and subpetaloid. Petals of the bivium very narrow, with the rows of pores extending in nearly parallel lines to the end; each poriferous area of about the same width as the interporiferous area; anterior pair shorter than the other petals and subelliptical in outline; the rows of pores converge slightly in their distal ends. Odd anterior petal of the same length as the petals of the bivium and of the same width as the anterior pair; the rows of pores with only a slight

tendency to converge at the extremity of the petal. Inferior surface nearly flat but with a slight concavity around the mouth. Peristome pentagonal in outline. Periproct situated above the ambitus, and below an overhanging rostrum; transversely elongate in outline.

Related forms.—This species is separated from *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew by its more elongate-shaped test, and by its pentagonal-shaped peristome. It closely resembles *Cassidulus* (*Rhynchopygus*) *patelliformis* (Bouvé) in shape, but may be distinguished by its posterior petals, which are not so nearly elliptical in outline.

Geologic horizon.—Vaqueros formation, Lower Miocene; associated with *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew and *Terebratalia kennedyi* (?) Dall.

Locality.—Cotypes from Santa Ynez River district, immediately east of Oso Creek, Santa Barbara County, California, Univ. Calif. loc. 3132.

CASSIDULUS (RHYNCHOPYGUS) MEXICANUS Kew, n. sp.

Plate 39, figures 4*a*, 4*b*, 4*c*

Holotype.—No. 11357 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of holotype: anteroposterior diameter 71.4 mm., transverse diameter 61.6 mm., greatest height 26.8 mm. Outline from above subelliptical; somewhat broader behind, and more pointed anteriorly. Upper surface regularly arched to the anterior extremity and posteriorly as far as the anal projection of the test; summit anterior to the center of the test. Apical system slightly anterior to the center of the upper surface, but behind the apex; madreporic area small. Petals lanceolate, slightly open at their ends, extending about five-eighths the distance to the ambitus; of unequal width, the anterior pair being the widest and the odd anterior one narrower than the posterior pair, but of the same length. Poriferous zones well developed and similar in all petals; anterior zones of the posterior pair of petals somewhat longer than the posterior zones; rows of pores in the zones not joining at their extremities. Periproct transversely elliptical and of large size; situated about one-third the elevation of the test above the ambitus; a slight anal projection immediately above; below the test slopes down to the margain, forming a shallow anal groove of the same width as the periproct. Tuberculation of the abactinal side consists of small scrobicular tubercles of uniform size. Inferior surface not exposed.

Related forms.—This form resembles closely the Recent species from the Gulf of California, *Rhynchopygus pacificus* Agassiz, but differs from the latter in being more narrowly elliptical in marginal outline; is more acutely pointed in front than behind; in that the anal opening is elliptical in shape and not crescent-shaped; and in that the petals are somewhat wider.

Geologic horizon.—Occurs in a horizon probably equivalent to the Gatun formation of the Gulf Coastal Plain, Lower Pliocene (?).

Locality.—Oyster bank, East San Ysidro, Lower California, Mexico.

CASSIDULUS (RHYNCHOPYGUS) YNEZENSIS Kew, n. sp.

Plate 39, figures *2a*, *2b*, *2c*, *2d*

Holotype.—No. 11345 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of holotype: anteroposterior diameter 25.6, transverse diameter 22.3 mm., greatest height 10.3 mm. Ambital outline broadly suboval, with the longitudinal diameter the greater. Upper surface rises regularly to a rather high apex, which is subcentral. Apical system eccentric to the anterior; four large genital pores present. Ambulacra subpetaloid; petals of the bivium longer than those of the trivium; the former wide open at the extremity, the rows of pores converging and diverging very slightly in their distal ends; anterior pair of petals wider than the posterior pair, due to the greater width of the interporiferous area; rows of pores diverge and then converge in the distal end to form an elliptical-shaped petal; odd anterior petal about one-half the width of the anterior paired petals, and with the rows of pores not so convergent at the end of the petal. Poriferous areas of all the petals narrow and of the same width; interporiferous areas of different widths, varying according to the breadth of the petal. Actinal surface flat. Peristome pentagonal in outline and transversely elongate; a phyllode is faintly visible. Periproct situated a short distance above the ambitus on the sloping posterior abactinal surface, and beneath an overhanging rostrum of the interambulacrum. Inferior surface covered with relatively large scrobiculate tubercles.

Related forms.—This species differs from *Cassidulus* (*Rhynchopygus*) *californicus* (Anderson) in having a less rounded and thinner margin; in that the test is relatively less elevated and has a sloping posterior abactinal surface; in that the petals of the trivium are rela-

tively wider; and in that in all the petals the rows of pores are more or less curved, whereas in those of the bivium they extend in parallel lines to the end. It may be compared to *Cassidulus* (*Rhynchopygus*) *lyelli* (Conrad), but differs in having a test which rises almost directly from the ambitus, whereas in the latter form the marginal area is thickened and has a rather flattened abactinal surface.

Geologic horizon.—Vaqueros formation, Lower Miocene; associated with *Cassidulus* (*Rhynchopygus*) *ellipticus* Kew and *Terebratalia kennedyi* (?) Dall.

Locality.—Holotype from Santa Ynez River, east side of Oso Creek, Santa Barbara County, California, Univ. Calif. loc. 3132.

Genus CATOPYGUS Agassiz

CATOPYGUS (?) CALIFORNICUS Kew, n. sp.

Plate 40, figures *2a, 2b, 2c, 2d*

Holotype.—No. 11014 (internal cast) Univ. Calif. Coll. Invert. Pal.

A cassidulid of small size. Measurements of specimen no. 11014: anteroposterior diameter 18.3 mm., transverse diameter 17 mm., greatest thickness 14 mm. Test globular in shape; outline from above subquadrate. Broadest anterior to the center of the test; somewhat truncated behind in the posterior odd interambulacral area. Upper surface greatly elevated to the summit, which coincides with the apical system. An interambulacral keel, faintly developed near the apical system, extends to the periproct, where it is quite prominent. Apical system subcentral. Ambulacra narrow and subpetaloid; two relatively large pores in each plate; pores in inner row circular, whereas those of outer row are oval; interporiferous area about the width of each poriferous area. Inferior surface slightly convex and somewhat keeled on posterior part. Peristome comparatively large, sunken, and with a posterior labrum; situated close to the anterior margin of the test. Periproct relatively large, round in outline, and placed high up on the posterior truncation of the test.

Geologic horizon.—Chico formation, Upper Cretaceous.

Locality.—Holotype from Contra Costa Hills, Alameda County, California.

CATOPYGUS (?) CAJONENSIS Kew, n. sp.

Plate 40, figures 1*a*, 1*b*, 1*c*

Holotype.—No. 11344 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of holotype: anteroposterior diameter 32 mm., transverse diameter 31 mm., greatest thickness 26 mm. Outline subcordate; broadest anterior to the center of the test. Upper surface regularly rounded to a central apex. Apical system anteriorly eccentric; four large genital pores present. Ambulacra subpetaloid; the double rows of pores extend in straight, slightly divergent lines to the ambitus; interporiferous areas slightly broader than one of the poriferous areas. Lower surface convex; peristome somewhat sunken; indistinct episternum present. Periproct round and situated well above the ambitus.

Related forms.—This form differs from *Catopygus* (?) *californicus* Kew in having a larger test, an eccentric apical system, and in lacking the posterior truncation of the test.

Geologic horizon.—Martinez group, Lower Eocene.

Locality.—Big Rock Creek, Los Angeles County, California, Univ. Calif. loc. 2249 (Dickerson).

Tribe SPATANGOIDEA Duncan

Family SPATANGIDAE Wright

Genus EPIASTER d'Orbigny

EPIASTER DEPRESSUS Kew, n. sp.

Plate 40, figures 3*a*, 3*b*, 3*c*, 3*d*

Cotypes.—Nos. 11011 and 11339 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimens 11011 and 11339, respectively: anteroposterior diameter 23 mm. and 31.3 mm., transverse diameter 22.5 mm. and approximately 26 mm., greatest height 10.2 mm. and 15.0 mm. Outline from above subcircular to cordiform; posterior extremity somewhat truncated. Upper surface regularly rounded and with a forward slope in the anterior portion of the test; sides rounded. Summit situated far back on the ridge, which extends from the apical system to the periproct. Apical system posteriorly eccentric. Petals symmetrical; bivium very short, being one-half the length of the anterolateral pair; petals of trivium of the same length.

Poriferous zones wide, each being about the same width as the interporiferous area; rows of pores do not tend to close in the odd anterior petal and only to a very slight degree in the lateral ones. Pores oval in shape, those of the inner rows being much more elongate than the outer ones. Petals situated in deep grooves, the odd anterior one continuing through a broad notch in the ambitus to the peristome on the under surface. Lower surface flat, except surrounding the mouth, where it is slightly depressed. Peristome transversely elongate, with prominent posterior labrum. Periproct small, transversely elongate, and placed high up on the posterior truncation of the test. Tuberculation prominent over the test; consists of irregularly placed primaries with numerous interspaced milliaries. The size of the tubercles varies; largest on the actinal surface, smallest near the ambitus, and larger again on the abactinal side. No fascioles present.

Related forms.—This form resembles *Schizaster lecontei* Merriam in general appearance, but may be separated by its more depressed test; narrower and less deeply sunken petals; and differs also in that it lacks the fascioles which characterize the genus *Schizaster.* From *Hemiaster californicus* Clark it differs in having much shorter petals in the bivium.

Geologic horizon.—Chico formation, Upper Cretaceous.

Locality.—Cotypes from northern California.

Genus HEMIASTER Desor

HEMIASTER ALAMEDENSIS Kew, n. sp.

Plate 40, figures *5a, 5b, 5c, 5d*

Holotype.—No. 11009 Univ. Calif. Coll. Invert. Pal.

Size rather large. Measurements of holotype: anteroposterior diameter 26.9 mm., transverse diameter 27.8 mm., greatest height 2.8 mm. Outline of test from above subcircular; longitudinal profile subrectangular. Test very tumid, with the posterior extremity truncated. Upper surface depressed and gently rounded to a low apex, which is situated far back on the small ridge that extends in the odd posterior interambulacral area from the apical system to the periproct. Apical system placed slightly to the posterior of the center of the test. Petals of the bivium about seven-tenths the length of the lateral petals

of the trivium, whereas the odd anterior one is slightly longer than the latter two. Poriferous areas large, each area being slightly wider than the interporiferous area. Petals symmetrical; inner rows of pores on the lateral petals extend in straight lines to the extremity of the petal, whereas the outer rows diverge markedly from the apical system, and then converge close to the inner rows at the end of the petal, making with the inner row a nearly perfect chord. Rows of pores of odd anterior petal continue in gradually divergent lines to the end, giving the petal a flaring appearance; lateral petals wider. All the petals are placed in shallow sulci, that of the odd anterior petal sunken to a less degree than the others. Under surface nearly flat with the exception of a large, broad, rounded keel which is produced posteriorly to the truncated portion of the test. Peristome small, suboval, and placed well toward the front; slightly sunken and with a prominent posterior labrum. Periproct small and situated high up on the truncated portion of the test.

Related forms.—This form may be easily distinguished from *Epiaster depressus* Kew by its much greater thickness, its very prominent keel on the actinal surface, and much wider petals. From *Hemiaster cholamensis* Kew it differs in having much broader petals, shallower petaliferous sulci, and the prominent actinal keel.

Geologic horizon.—Chico formation, Upper Cretaceous.

Locality.—Shepherd Canyon, Contra Costa Hills, Alameda County, California.

HEMIASTER CALIFORNICUS W. B. Clark

Plate 40, figures 4*a*, 4*b*, 4*c*

Hemiaster californicus Clark. Johns Hopkins University Circ., vol. 10, no. 87, 1891, p. 77.

Hemiaster californicus Clark. *Ibid.*, vol. 12, no. 103, 1893, p. 52.

Hemiaster californicus Clark. U. S. Geol. Surv. Bull., no. 97, 1893, p. 90, pl. 49, figs. 1*a*, 1*b*, 1*c*.

Hemiaster californicus. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 96, pl. 50, figs. 1*a*, 1*b*, 1*c*, 1*d*.

Holotype.—No. 31203 U. S. Nat. Mus. *Figured specimen,* no. 11013 Univ. Calif. Coll. Invert. Pal.

An echinoid of medium size. Measurements of specimen no. 11013: anteroposterior diameter approximately 28.5 mm., transverse diameter 28.2 mm., greatest thickness 15 mm. Outline from above subhexagonal

to cordiform; posterior portion slightly truncated. Test greatly depressed; upper surface rising gently from the ambitus to the summit, which is immediately behind the apical system on the small odd posterior interambulacral ridge. Petals symmetrical; those of the bivium slightly more than seven-tenths the length of the anterior lateral petals. Poriferous area broad, each being as wide as the interporiferous area. Inner rows of pores in the lateral petals extend in approximately parallel lines to the end, whereas the outer rows diverge and then converge again close to the inner rows; odd anterior petal slightly narrower than the lateral petals of the trivium and the rows of pores diverge slightly to their extremities. All the petals situated in rather deep sulci, that of the odd anterior one continuing through a broad, well defined notch in the ambitus to the peristome on the lower surface. Apical system small and posterior to the center of the test. Under side nearly flat, with a slight tendency to be convex. Peristome transversely suboval and somewhat sunken, with a distinct posterior labrum. Periproct placed high up on the posterior truncation of the test. The test covered by irregularly spaced, perforate, primary tubercles interspaced with numerous milliaries.

Related forms.—*Hemiaster californicus* closely resembles the northern California species, *Epiaster depressus* Kew, but differs in the less strongly depressed test, and in that the petals of the bivium are of greater length.

Geologic horizon.—Chico formation, Upper Cretaceous.

Localities.—Holotype from Redding, Shasta County, California; figured specimen from Santa Ana Mountains, Orange County, California, Univ. Calif. loc. 2139.

HEMIASTER CHOLAMENSIS Kew, n. sp.

Plate 41, figures 1*a*, 1*b*, 1*c*, 1*d*

Cotypes.—Nos. 11338 and 11343 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of holotype: anteroposterior diameter 25.3 mm., transverse diameter 27 mm., greatest height 20.7 mm. Ambital outline subcircular to subpentagonal; posterior end slightly truncated. Sides of test nearly vertical, with the upper surface low, regularly rounded, and declining toward the anterior portion of the test. A small, sharp ridge is present in the posterior interambulacral area, which extends from the apical system to the periproct. Summit slightly posterior to the apical system. Apical system very small, and

situated immediately posterior to the center of the test. Petals of the bivium slightly less than one-half the length of the anterior pair; odd anterior one longest; paired petals narrow and the anterior pair bent slightly backward; odd anterior petal much wider. Poriferous areas wide. All petals situated in deep sulci, that of the odd anterior one continuing through a deep notch in the ambitus to the peristome on the inferior surface. Under side usually somewhat convex, and produced posteriorly into a small knob. Peristome small, semicircular in outline, and with a prominent posterior labrum. Periproct of moderate size, suboval in outline, the greatest diameter being in a vertical direction; placed high up on the posterior truncation of the test.

Related forms.—Among the California forms *Hemiaster cholamensis* is most closely allied to *H. alamedensis* Kew, but may be distinguished by its very short posterior petals, deeper sulci in which the petals are placed, narrower petals, and a much less prominent knob on the lower posterior portion of the test. The Texan form, *H. bexari* Clark, from the Washita group of the Comanche series, may be compared with this species, but *H. cholamensis* differs in having a less rounded transverse profile, and in that the anterior petals are narrower and those of the bivium are shorter.

Geologic horizon.—Chico (?) formation, Upper Cretaceous.

Locality.—Holotype from center of Sec. 5, T. 24 S., R. 16 E., M. D. B. and M., in southeast corner of Monterey County, California, Univ. Calif. loc. 3141.

HEMIASTER OREGONENSIS Kew, n. sp.

Plate 41, figures *2a*, *2b*, *2c*, *2d*

Cotypes.—Nos. 11039 and 11040 Univ. Calif. Coll. Invert. Pal.

Size relatively large. Measurements of type: anteroposterior diameter 32 mm., transverse diameter 32.5 mm., greatest height 14 mm. Outline from above subcordate; posterior extremity slightly truncated. Test considerably depressed, with upper surface gently arched; a low ridge is present in the odd anterior interambulacral area which forms the highest portion of the test. Apical system central or subcentral; petals large and well developed; those of the bivium two-thirds the length of the anterior pair, and somewhat narrower. Paired petals subelliptical in outline; outer rows of pores forming regular, curving lines, while the inner rows extend in approximately parallel lines

for their entire length. Posterior. pair of petals bent slightly backward. Pores elongate and conjugate. Odd anterior petal differs from the others in that both rows of pores extend in parallel lines nearly to the ambitus; pores more nearly round than in the others. All petals situated in rather deep sulci, the odd anterior one continuing to the mouth on the under surface and forming a broad notch in the ambitus. Peristome sunken and placed close to the anterior margin, small in size, and transversely suboval in outline. Posterior labrum present. Actinal surface nearly flat, with a slight tendency to form a broad keel. Periproct small, round, and situated high up on the posterior truncation of the test. Tuberculation not shown.

Related forms.—Among west coast spatangids this form most closely resembles *Hemiaster californicus* Clark. *H. oregonensis* differs in that the apical system is not so eccentric, the posterior pair of petals are more divergent, and the odd interambulacral ridge is not so well developed and acute.

Geologic horizon.—Cretaceous.

Locality.—Cotypes from near Old Dollarhide tollgate on Pacific Highway, Jackson County, Oregon, Univ. Calif. loc. 3142.

Genus SCHIZASTER Agassiz

SCHIZASTER CALIFORNICUS (Weaver)

Plate 41, figure 4

Linthia (?) californica Weaver. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1908, pp. 273–274, pl. 21, fig. 2.

Brissopsis californica. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 705.

Linthia ? californica. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 214–215, pl. 98, fig. 4.

Holotype.—A badly crushed specimen no. 11349 Univ. Calif. Coll. Invert. Pal.; *neotype,* no. 11259 Univ. Calif. Coll. Invert. Pal.

Size of test large. Measurements of specimen no. 11259: anteroposterior diameter 43 mm., transverse diameter 32 mm., greatest height approximately 10 mm. Ambital outline subcircular, somewhat undulating, with a broad notch at the distal end of the anterior sulcus; an indistinct notch is present in the odd posterior interambulacral area. Upper surface considerably elevated; interambulacral areas highly ridged, between which are deep, broad ambu-

lacral sulci; odd anterior sulcus nearly twice the width of the lateral ones. Apical system posteriorly eccentric, small, and sunken to the same level with the petals; four large genital pores present. Petals unequal in length; those of the bivium shorter than the anterior lateral pair, but of the same width. Inner rows of more or less rounded pores extend in approximately parallel lines to the end of the petal; outer rows of elongate pores diverge at first and then converge within the distal half, nearly closing with the inner rows at the end of the petal. Interporiferous area markedly narrow; equal to about one-half the width of each poriferous area. Odd anterior petal obliterated on the specimens at hand. Inferior surface flattened. Peristome relatively large, transversely elongate, situated well toward the anterior portion of the test, sunken, and with a prominent posterior labrum.

Related forms.—This species may be readily distinguished from other California schizasters by its long posterior petals, very broad petals, and by its depressed test.

Geologic horizon.—Agasoma gravidum zone, San Lorenzo series, Oligocene.

Localities.—Holotype from west side of Bear Creek, Contra Costa County, California; figured specimen from same horizon Univ. Calif. loc. 3055.

SCHIZASTER CORDIFORMIS Kew, n. sp.

Plate 42, figures 1*a*, 1*b*, 1*c*, 1*d*

Holotype.—No. 11388 Univ. Calif. Coll. Invert. Pal.

Test small, usually smaller than that of *Schizaster lecontei* Merriam. Measurements of specimen 11388: anteroposterior diameter 24 mm., transverse diameter 24.3 mm., greatest height 14.7 mm. Outline from above cordiform, with posterior end slightly truncated. Apical system small and slightly eccentric anteriorly; summit behind the apical system and about midway to the posterior margin on the prominent ridge which extends from the apical system to the periproct. Upper surface depressed and sloping rather steeply from the apex to the anterior margin, so that the cross-section of the test is semicircular in outline. Ambulacra petaloid. Petals of the bivium subelliptical in shape and comparatively narrow; anterolateral petals of the same width and about twice as long as the posterior pair. Petals imperfectly preserved so that the details can not be made out clearly.

Odd anterior petal slightly longer than the others. All petals in deep sulci, the odd anterior one continuing beyond the petal through a notch in the margin to the peristome on the under side. Peristome situated well forward on the lower surface; large, semilunar in shape, and with prominent projecting labrum. Lower surface very slightly convex and with weakly developed episternum. Periproct small, round, and situated high up on the posterior truncation of the test. Tubercles on upper surface small and numerous; those on the under side somewhat larger and not so crowded; those on the actinal plastron considerably larger than the others; all with definite scrobicules.

Related forms.—This species differs from *Schizaster diabloensis* Kew in having a more strongly depressed test, longer and narrower posterior petals, and usually a more nearly cordiform outline. From *S. lecontei* Merriam and *S. martinezensis* Kew it is easily distinguished by its less elongate and more depressed test.

Geologic horizon.—Lower part of the Martinez group, Lower Eocene.

Locality.—Univ. Calif. loc. 1743, north side of Mount Diablo.

SCHIZASTER DIABLOENSIS Kew, n. sp.

Plate 41, figures *5a, 5b, 5c*

Schizaster lecontei. Dickerson, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1914, pp. 121–122, pl. 6, fig. 7.

Holotype.—No. 11387 Univ. Calif. Coll. Invert. Pal.

Test of medium size. Measurements of specimen 11387: anteroposterior diameter 24.2 mm., transverse diameter 26.7 mm., greatest height 20.2 mm. Outline from above subcircular to slightly cordiform, the transverse diameter often being greater than the anteroposterior diameter. Posterior end very slightly truncated, if at all. Apical system very small and somewhat sunken; posteriorly eccentric. Summit behind the apical system on a low ridge which extends from the apical system to the periproct. Upper surface slopes gradually from the apex to the anterior part of the ambitus, but steeply to the posterior part. Sides of test broadly rounded except in the posterior portion, where they are nearly vertical. Ambulacra petaloid. Petals of the bivium very short and subelliptical in outline; anterolateral petals broad and nearly three times the length of the posterior pair. Inner rows of pores of paired petals diverge slightly at first and then continue in nearly parallel lines to the end, whereas the outer rows

diverge to a greater degree and then converge close to the inner rows at the end of the petal. Interporiferous areas as wide as the poriferous areas; pores in both rows transversely elongate. Odd anterior petal longer than the others and wider; both rows of pores diverge continuously to their extremities. All petals in deep sulci, the odd anterior one continuing beyond the petal through a deep notch in the ambitus to the peristome on the under surface. Lower surface faintly convex. Peristome situated well forward in a strongly developed transverse depression. A prominent labrum is present which is produced posteriorly into a moderately developed episternum. Periproct small and round; situated high up on the posterior part of the test. Tubercles on upper surface very small and crowded; larger and less numerous on the under surface; largest immediately anterior to the peristome.

Related forms.—*Schizaster lecontei* Merriam differs from *S. diabloensis* mainly in having a more elongate test, in that the petals of the bivium are slightly longer, and the apical system is central. *S. diabloensis* Kew may be separated from *S. cordiformis* Kew in having a more tumid test, more eccentric apical system, and in that the posterior end of the test is not so broadly truncated.

Geologic horizon.—Common in Meganos group, Middle Eocene; associated with *Turritella andersoni* Dickerson.

Localities.—Type from SW. ¼ of Sec. 11, northeast of Wall Point, south side of Mount Diablo, Univ. Calif. loc. 1427 (108). Occurs also at Marysville Buttes, Santa Ynez Mountains, and on both north and south sides of Mount Diablo, California.

SCHIZASTER LECONTEI Merriam

Plate 41, figures *3a, 3b, 3c, 3d*

Schizaster (*?*) sp. Merriam, Jour. Geol., vol. 5, 1897, p. 773.
Schizaster lecontei Merriam. Proc. Calif. Acad. Sci., ser. 3, Geol., vol. 1, 1899, pp. 164–165, pl. 21, figs. 1, *1a*.
Not *Schizaster lecontei.* Dickerson, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, 1914, pp. 121–122, pl. 6, fig. 7.
Schizaster lecontei. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 697.
Schizaster lecontei. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, pp. 151–152, pl. 69, figs. *3a, 3b*.

Holotype.—No. 11026; *figured specimen,* no. 11341 Univ. Calif. Coll. Invert. Pal.

Test of small size. Average measurements: anteroposterior diameter 22 mm., transverse diameter 20 mm., greatest height 14 mm.

Outline as seen from above suboval to cordiform; posterior end more or less truncated. Apical system very small, sunken, and central; summit placed behind apical system on the sharp ridge which extends from the apical system to the periproct. Upper surface slopes gradually to the anterior margin from the apex. Sides of the test broadly rounded, except in the posterior portions, where they are nearly vertical. Ambulacra petaloid. Petals of the bivium very short and subelliptical to rounded in outline; anterolateral petals broad and twice the length of the posterior pair. Inner rows of pores of paired petals diverge slightly at first, and then continue in parallel lines to the end of the petal, while outer rows diverge considerably more and then converge close to the inner rows. Poriferous areas wide, each being as wide as the interporiferous area; pores in both rows transversely elongate. Odd anterior petal longer than the others; both rows of pores round and diverge continuously to their extremities. All petals in deep sulci, the odd anterior one continuing through a deep notch in the margin to the under side. Lower surface slightly convex. Peristome situated well forward in a distinct transverse depression having a prominent labrum which is produced posteriorly into a well defined episternum. Periproct small, round, and situated high up on the posterior truncation of the test. Peripetalous fasciole broad and sinuous; lateral fasciole narrower, but distinct. Tubercles on upper surface small and crowded, but become larger in the grooves of the trivium and on the anterior portion of the test; those of the under side also larger and less numerous; those of the actinal plastron regularly placed in anteriorly convex rows.

Related forms.—*Schizaster lecontei* Merriam is most closely related to *S. martinezensis* Kew, from which it differs in having its apical system less eccentric to the posterior of the center of the test; and in that the petals of the trivium are shorter and the petals of the bivium longer.

Geologic horizon.—Martinez group, Lower Eocene; occurring in the Solen stantoni zone, Trochoscyathus zitteli zone, and Meretrix dalli zone; associated with *Schizaster cordiformis* Kew.

Localities.—Type from one and one-quarter miles southeast of Muir Station, on hillside northeast side of Martinez-Walnut Creek road, 75 feet above road, Univ. Calif. loc. 337; figured specimen from Muir Syncline near Vine Hill Station, Contra Costa County, California. Also occurs at Mount Diablo, Contra Costa County, California; Lower Lake, Lake County, California.

SCHIZASTER MARTINEZENSIS Kew, n. sp.

Plate 42, figures 2*a*, 2*b*, 2*c*, 2*d*

Holotype.—No. 11342 Univ. Calif. Coll. Invert. Pal.

Test large. Measurements of holotype: anteroposterior diameter 40.9 mm., transverse diameter 32.3 mm., greatest height 21.5 mm. Marginal outline subelliptical, slightly truncated in the posterior interambulacral area; test moderately inflated, much less in front than behind. Apical system situated about one-third the distance from the center of the test to the posterior margin. Upper surface rises gradually from the margin to the apex, which is placed behind the apical system on a rather low, broad ridge, extending in the odd interambulacral area from the apical system to the posterior margin. Petals of bivium less than one-third the length of the anterior pair; anterior rows of pores in lateral petals of the trivium converge much more than the posterior rows, nearly closing at the ends of the petals. Odd anterior petal longer than the others, much broader, and with pores rounded instead of oval in outline; poriferous areas about as broad as the interporiferous area at their widest part. Lateral petals placed in narrow grooves; the poriferous areas situated on the sides of the groove, giving the petals the appearance of being quite narrow; odd anterior petal in a broad, deep groove, which narrows near the margin and passes through a shallow marginal notch to the mouth on the under side. Inferior surface very slightly convex, with actinal plastron well developed. Peristome semicircular and sunken, with a prominent posterior labrum. Periproct small, and situated high up on the posterior truncation of the test. Tuberculation of the upper surface not preserved; tubercles of lower surface small, and not numerous; more crowded on the actinal plastron, but smaller toward the posterior end.

Related forms.—This form is closely related to *Schizaster lecontei* Merriam, but it differs from the latter in having a more eccentric apical system, longer anterolateral petals with shorter ones in the bivium, and in having much narrower grooves in which the paired petals are situated.

Geologic horizon.—Martinez group, Lower Eocene; associated with *Schizaster cordiformis* Kew.

Localities.—Holotype from Swett's Ranch, on coral reef, south of Martinez, Contra Costa County, California, Univ. Calif. loc. 241.

SCHIZASTER STALDERI Weaver

Plate 42, figures *3a, 3b, 3c, 3d*

Schizaster (?) stalderi Weaver. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1908, p. 274, pl. 21, fig. 3.
Schizaster stalderi. Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 705.
Schizaster (?) stalderi. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 221, pl. 103, fig. 2.

Holotype.—No. 11019 Univ. Calif. Coll. Invert. Pal.

Test attaining rather large size. Average measurements: antero-posterior diameter 26 mm., transverse diameter 39 mm., greatest height 15 mm. Marginal outline subelliptical to subcordate, with the greatest width anterior to the center of the test. Apical system posteriorly eccentric. Summit coincides with the apical system or is immediately posterior to it; posterior odd interambulacrum elevated slightly to form an indistinct ridge. Ambulacra petaloid; petals of bivium slightly less than one-half the length of the anterolateral petals, and extending about three-fifths the distance to the margin. Inner rows of pores in paired petals converge but little at their extremities; outer rows converge close to the inner rows near the end of the petals. Anterior pair of lateral petals extend close to the margin and are narrower than the posterior pair. Interporiferous areas of lateral petals narrow, being about the same width as one of the poriferous areas. Odd anterior petal considerably wider than the others, due to the greater width of the interporiferous area; extends nearly to the anterior margin; rows of pores converge but little at their extremities. All petals situated in deep sulci, the anterior pair being slightly shallower than the others; the odd anterior one continues to the under side, cutting the anterior margin in a prominent notch. Inferior surface flat or somewhat convex; episternum prominent and elevated. Peristome placed close to anterior margin in a deep transverse groove which extends almost across the test. Periproct large, round, and situated well up on the posterior truncation of the test. Tubercles similar over the test, except on the actinal plastron where they are larger and less crowded.

Related forms.—This form does not seem to be closely allied to any other *Schizaster* on the Pacific Coast. It is easily distinguishable from *Schizaster lecontei* Merriam by its more depressed test, longer petals in the bivium, and by the presence of an actinal transverse groove in which the peristome is situated.

Geologic horizon.—Wildcat series, Upper Pliocene.

Locality.—Holotype from near Cape Mendocino; also occurs at mouth of Bear River, Humboldt County, California.

Genus SPATANGUS Lamarck

SPATANGUS PACHECOENSIS Pack

Plate 42, figures *4a, 4b, 4c, 4d*

Spatangus (?) *pachecoensis* Pack. Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 1909, p. 276, pl. 23, figs. 4, 5.

Spatangus (?) *pachecoensis.* Lambert, Rev. Crit. paléozoölogie, vol. 4, 1910, p. 55.

Spatangus (?) *pachecoensis.* Stefanini, Boll. Soc. geol. ital., vol. 30, 1911, p. 705.

Spatangus ? pachecoensis. Clark and Twitchell, U. S. Geol. Surv. Mon., vol. 54, 1915, p. 156.

Cotypes.—Nos. 11330 and 11331; *topotype,* specimen no. 11020 Univ. Calif. Coll. Invert. Pal.

Test small. Measurements of specimen no. 11020: anteroposterior diameter 23.7 mm., transverse diameter 25.6 mm., greatest height 10.6 mm. Marginal outline subcordate, slightly truncated in the odd posterior interambulacrum, and deeply notched in the anterior ambulacral area. Apical system eccentric anteriorly. Upper surface broadly convex to the apex, which is situated about half way between the apical system and the posterior margin; somewhat flattened on top. Petals of the bivium broad and elliptical in outline; rows of pores converge but little at their extremities. Anterior lateral petals slightly narrower and shorter than those of the bivium; angle between the former nearly 180 degrees, distal ends curved forward. Posterior rows of pores regularly curved; anterior rows diverge from the posterior rows markedly at first, then continue in almost straight lines to the distal ends of the petals, where they finally curve forward. Odd anterior petal short, wide, and placed in a broad, shallow sulcus which becomes deeper at the margin, passes through a marginal notch, and continues on the under side to the peristome. Inferior surface somewhat concave near the mouth. Episternum raised and produced posteriorly to form a broad keel. Peristome eccentric anteriorly, large, semicircular in outline, and with prominent posterior labrum. Periproct large, round, and placed high up on the posterior truncation of

the test, and surrounded by an area which is considerably swollen. Large primary scrobicular tubercles are present in the inter-radial area, limited by the length of the petals; the remainder of the tuberculation could not be made out. Subanal fasciole present, but no peripetalous fasciole could be distinguished.

Geologic horizon.—Tejon group, Upper Eocene; (?) Meganos group, Middle Eocene.

Localities.—Cotypes and topotype from Santa Fé Railroad cut, west of Vine Hill Station, Concord quadrangle, Contra Costa County, California; a specimen, probably *Spatangus pachecoensis* Pack, occurs in Meganos formation near head of Aliso Canyon (West) in Santa Susana quadrangle, Los Angeles County, California (loc. 549 Calif. Acad. Sci. Coll.).

Transmitted May, 1917.

EXPLANATION OF PLATES

EXPLANATION OF PLATE 3

Fig. 1. *Cidaris tehamaensis* W. B. Clark. Holotype, specimen 31195, U. S. Nat. Mus. Shelton's Ranch, Tehama County, Calif. Knoxville formation, Lower Cretaceous. Natural size. Photographed by U. S. Geological Survey.

Fig. 2*a*. *Cidaris martinezensis* Kew, n. sp. Specimen 11400, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Swett's Ranch, Contra Costa County, Calif., Univ. Calif. loc. 241. Martinez group, Lower Eocene. × 3.

Fig. 2*b*. *Cidaris martinezensis* Kew, n. sp. Same specimen. Lateral surface of test. × 3.

Fig. 2*c*. *Cidaris martinezensis* Kew, n. sp. Same specimen. Lower surface of test. × 3.

Fig. 3. *Cidaris merriami* Arnold. Specimen 11401, Univ. Calif. Coll. Invert. Pal. Lateral surface of spine. North side Mount Diablo, Contra Costa County, Calif., Univ. Calif. loc. 1592. Martinez group, Lower Eocene. × 2.

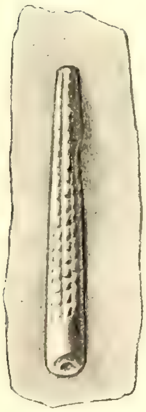
Fig. 4. *Cidaris lorenzanus* (Arnold). Holotype, specimen 1056 U. S. Nat. Mus.; in Leland Stanford Jr. Univ. Coll. Pal. Lateral surface of spine. × 2. Bear Creek, Santa Cruz County, Calif., Stanford Univ. loc. 109. San Lorenzo series, Upper Oligocene.

Fig. 5. *Tripneustes* (*Hipponoë*) *californicus* (Kew). Holotype, specimen 10055, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower division of the Carrizo Creek beds, Pliocene. Natural size.

2a

2c

2b



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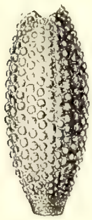

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EXPLANATION OF PLATE 4

Fig. 1*a*. *Strongylocentrotus franciscanus* A. Agassiz. Specimen 11389, Univ. Calif. Coll. Invert. Pal. Upper surface of test. × 1½. Ventura County, Calif. Upper Fernando formation, Upper Pliocene.

Fig. 1*b*. *Strongylocentrotus franciscanus* A. Agassiz. Same specimen. Lower surface of test. × 1½.

Fig. 1*c*. *Strongylocentrotus franciscanus* A. Agassiz. Same specimen. Lateral surface of test. × 1½.

Fig. 2*a*. *Sismondia(?) arnoldi* Twitchell. Holotype specimen 165538, U. S. Nat. Mus. Upper surface of test. × 2. Coalinga district, Fresno County, Calif. Etchegoin formation, Lower Pliocene.

Fig. 2*b*. *Sismondia(?) arnoldi* Twitchell. Same specimen. Lower surface of test. × 2.

Fig. 3*a*. *Sismondia (?) coalingaensis* Twitchell. Holotype, specimen 165717, U. S. Nat. Mus. Upper surface of test. × 2. Coalinga district, Fresno County, Calif. Etchegoin formation, Lower Pliocene.

Fig. 3*b*. *Sismondia(?) coalingaensis* Twitchell. Same specimen. Lower surface of test. × 2.

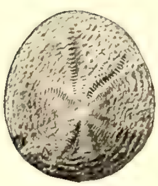

1a


1b


1c


2a


2b


3a

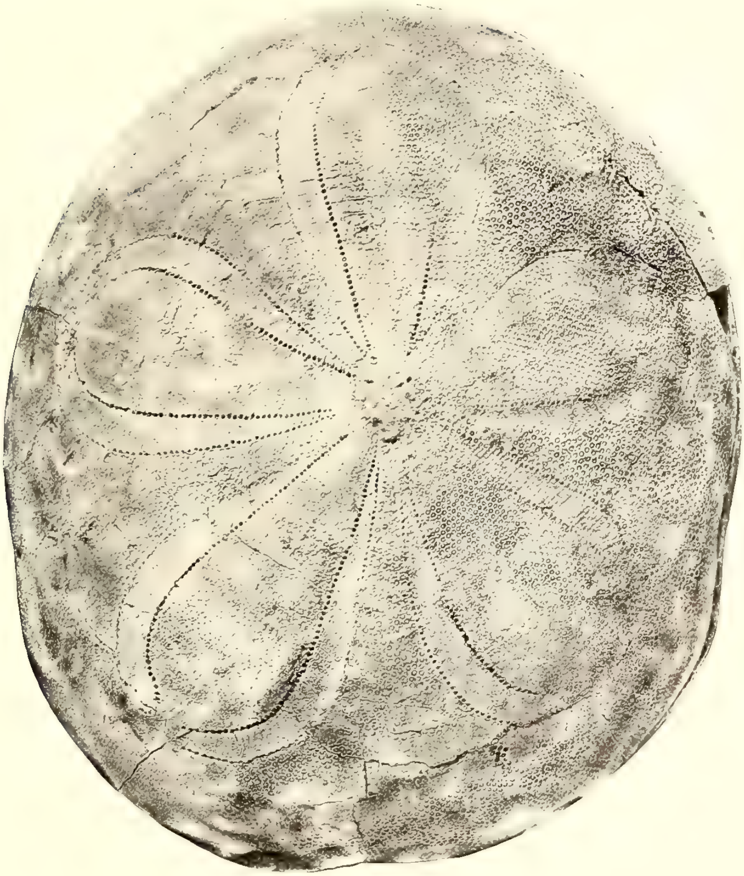

3b

EXPLANATION OF PLATE 5

Figures approximately natural size.

Fig. 1*a*. *Clypeaster bowersi* Weaver. Specimen 10059, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower division of the Carrizo Creek beds, Pliocene.

Fig. 1*b*. *Clypeaster bowersi* Weaver. Same specimen. Lateral surface of test.



1a

1b

EXPLANATION OF PLATE 6

Figure approximately natural size

Fig. 1. *Clypeaster bowersi* Weaver. Cotype, specimen 10060, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower division of the Carrizo Creek beds, Pliocene.

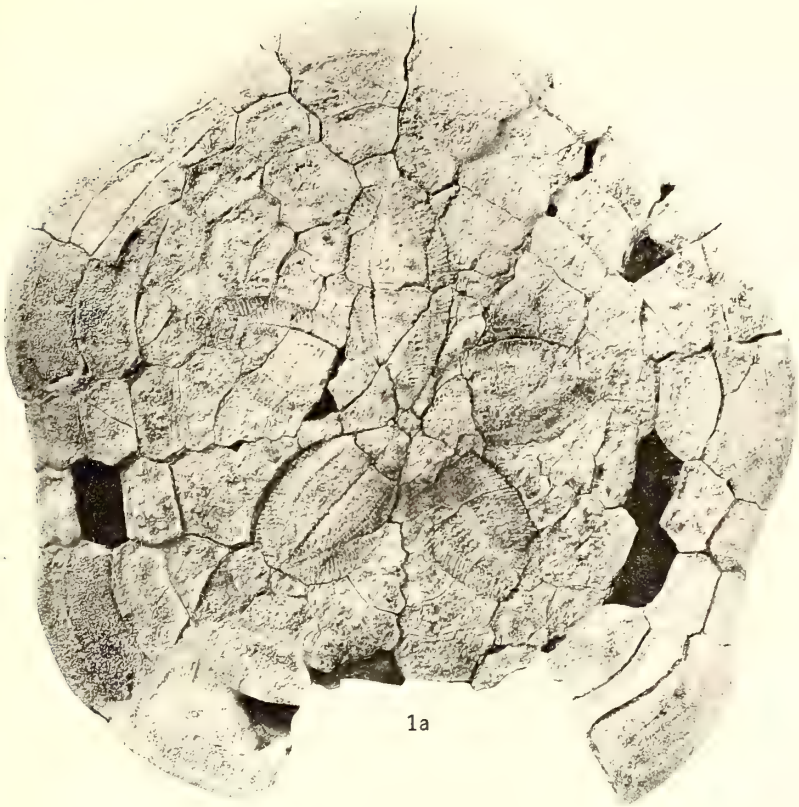
EXPLANATION OF PLATE 7

Fig. 1*a*. *Clypeaster deserti* Kew. Holotype, specimen 10056, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Natural size. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower division of Carrizo Creek beds, Pliocene.

Fig. 1*b*. *Clypeaster deserti* Kew. Same specimen. Lateral surface of test. Natural size.

Fig. 2*a*. *Clypeaster carrizoensis* Kew. Holotype, specimen 10047, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 738. $\times 1\frac{1}{2}$. Lower division of Carrizo Creek beds, Pliocene.

Fig. 2*b*. *Clypeaster carrizoensis* Kew. Same specimen. Lateral surface of test. $\times 1\frac{1}{2}$.



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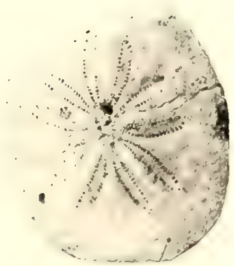

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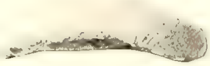


2b

EXPLANATION OF PLATE 8

Figures approximately natural size.

Fig. 1*a*. *Scutella coosensis* Kew, n. sp. Holotype, specimen 446, Calif. Acad. Sci. Coll. Invert. Pal. Upper surface of test. West of Yokam Point, Coos County, Oregon, Calif. Acad. Sci. loc. 9. Uppermost Eocene.

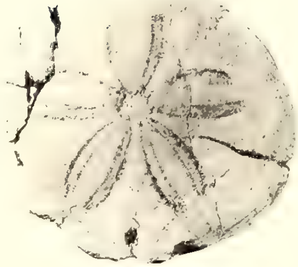
Fig. 1*b*. *Scutella coosensis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 2*a*. *Scutella newcombei* Kew, n. sp. Holotype, specimen 11356, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Slide Hill Beach, Vancouver Island, B. C. Sooke beds, Lower Oligocene.

Fig. 2*b*. *Scutella newcombei* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 3. *Scutella vaquerosensis* Kew, n. sp. Cotype, specimen 11404, Univ. Calif. Coll. Invert. Pal. Upper surface of test showing detail of petals. West side of Salinas River, Monterey County, Calif. Vaqueros formation, Lower Miocene.

1a



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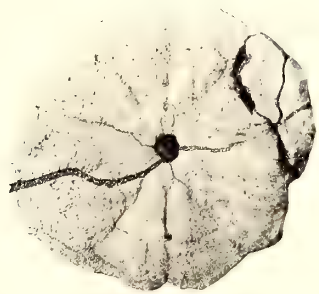

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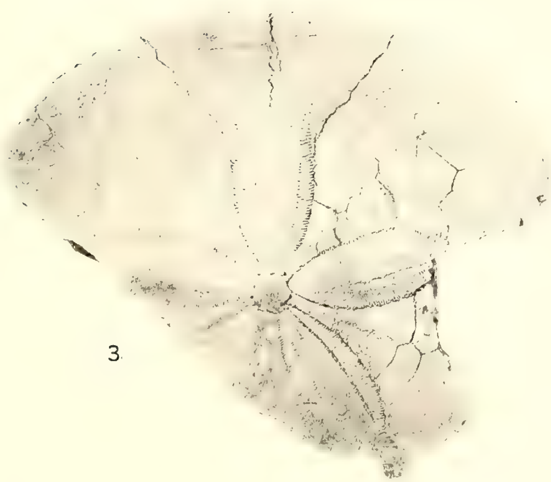


3

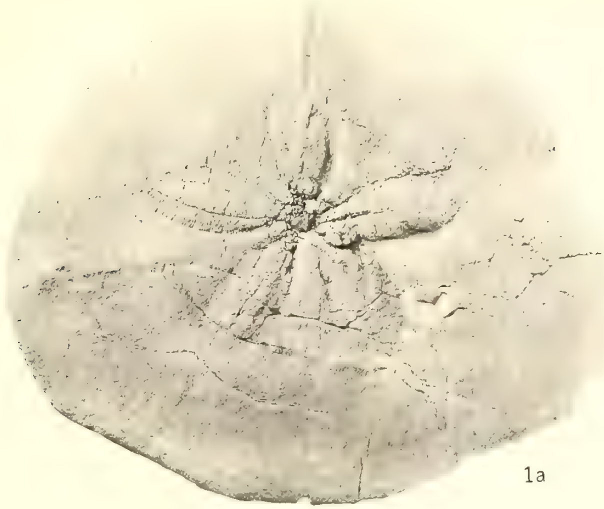
EXPLANATION OF PLATE 9

Figures approximately natural size.

Fig. 1*a*. *Scutella vaquerosensis* Kew, n. sp. Cotype, specimen 447, Calif. Acad. Sci. Coll. Invert. Pal. Upper surface of test. Vaqueros Creek, San Luis Obispo County, Calif., Calif. Acad. Sci. loc. 140. Vaqueros formation, Lower Miocene.

Fig. 1*b*. *Scutella vaquerosensis* Kew, n. sp. Cotype, specimen 447, Calif. Acad. Sci. Coll. Invert. Pal. Lateral surface of test.

Fig. 1*c*. *Scutella vaquerosensis* Kew, n. sp. Cotype, specimen 11403, Univ. Calif. Coll. Invert. Pal. Lower surface of test. West side of Salinas Valley, Calif. Vaqueros formation, Lower Miocene.



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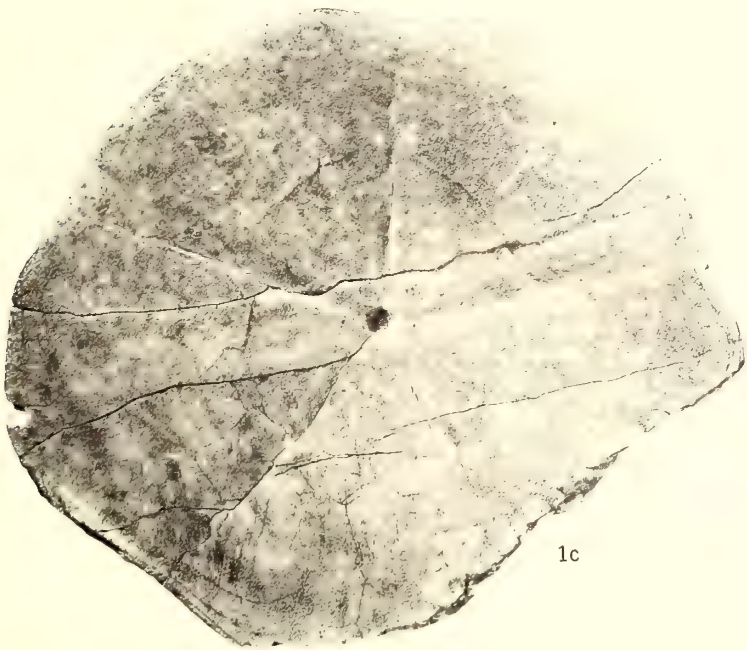


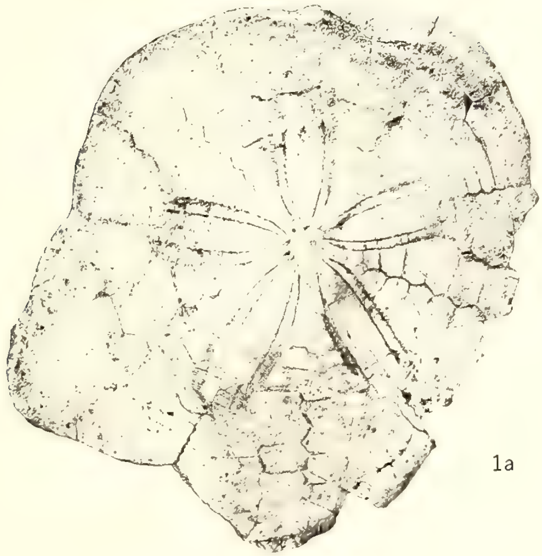
1c

EXPLANATION OF PLATE 10

Figures approximately natural size.

Fig. 1*a*. *Scutella norrisi* Pack. Lectotype, specimen 11027, Univ. Calif. Coll. Invert. Pal. Upper surface of test. San Joaquin Hills, Orange County, Calif., Univ. Calif. loc. 1157. Vaqueros formation, Lower Miocene.

Fig. 1*b*. *Scutella norrisi* Pack. Holotype, specimen 11028, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Near Stone Canyon Coal Mine, Monterey County, Calif. Vaqueros formation, Lower Miocene.



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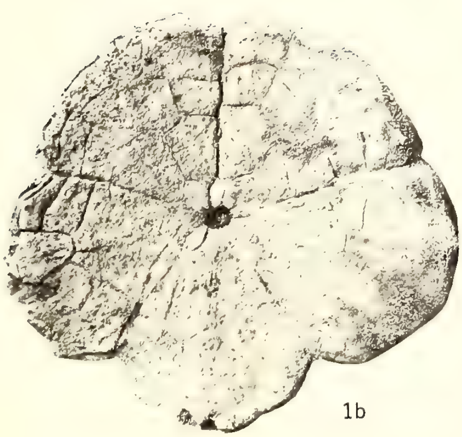


1b

EXPLANATION OF PLATE 11

Figures approximately natural size.

Fig. 1*a*. *Scutella blancoensis* Kew, n. sp. Cotype, specimen 11358, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Cape Blanco, Oregon. San Lorenzo series, Oligocene.

Fig. 1*b*. *Scutella blancoensis* Kew, n. sp. Cotype, specimen 11359, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Same locality.

Fig. 1*c*. *Scutella blancoensis* Kew, n. sp. Specimen 11359. Lower surface of test.

Fig. 2*a*. *Scutella fairbanksi* Arnold. Holotype, specimen 11017, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Torrey Canyon, Ventura County, Calif. Vaqueros formation, Lower Miocene.

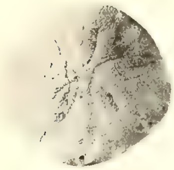
Fig. 2*b*. *Scutella fairbanksi* Arnold. Specimen 11017. Lower surface of test.

Fig. 2*c*. *Scutella fairbanksi* Arnold. Specimen 11360, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Shiells Canyon, south side of Santa Clara Valley, Ventura County, Calif., Univ. Calif. loc. 3075. Vaqueros formation, Lower Miocene.

Fig. 3*a*. *Scutella fairbanksi santanensis* Kew, n. var. Cotype, specimen 11362, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Santa Ana Mountains, Orange County, Calif., Univ. Calif. loc. 2339. Vaqueros formation, Lower Miocene.

Fig. 3*b*. *Scutella fairbanksi santanensis* Kew, n. var. Cotype, specimen 11361, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Univ. Calif. loc. 2339.

Fig. 3*c*. *Scutella fairbanksi santanensis* Kew, n. var. Specimen 11361. Lower surface of test.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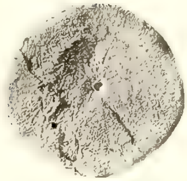
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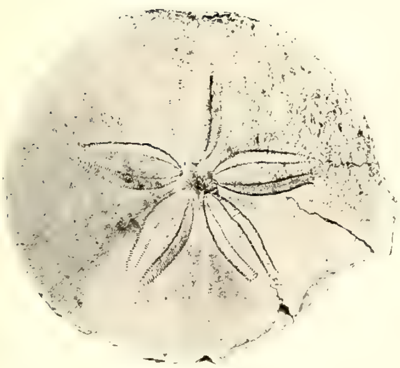
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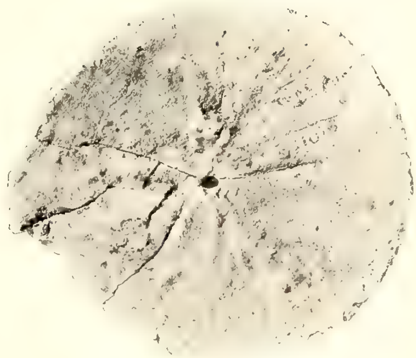
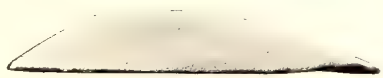

2b


3b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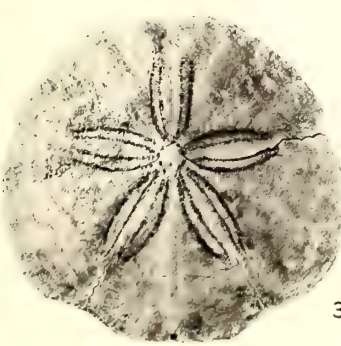
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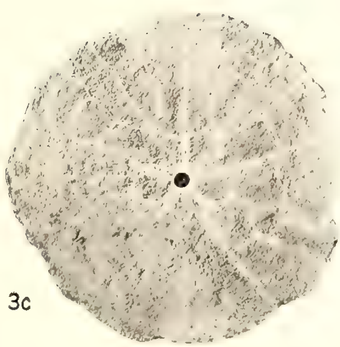

3c

EXPLANATION OF PLATE 12

Fig. 1*a*. *Scutella andersoni* Twitchell. Specimen 11363, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Natural size. Tejon Hills, Kern County, Calif., Univ. Calif. loc. 3358. Vaqueros formation, Lower Miocene.

Fig. 1*b*. *Scutella andersoni* Twitchell. Specimen 11364, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Natural size. Same locality.

Fig. 1*c*. *Scutella andersoni* Twitchell. Specimen 11364. Lateral surface of test. Natural size.

Fig. 2*a*. *Scutella tejonensis* Kew, n. sp. Holotype, specimen 11365, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Natural size. Tejon Hills. Kern County, Calif., Univ. Calif. loc. 3358. Vaqueros formation, Lower Miocene.

Fig. 2*b*. *Scutella tejonensis* Kew, n. sp. Specimen 11365. Lateral surface of test. Natural size.

Fig. 3*a*. *Scutella merriami* (F. M. Anderson). Cotype, specimen 53, Calif. Acad. Sci. Coll. Invert. Pal. Upper surface of test. × 1½. Coalinga District, Fresno County, Calif. Monterey group, Lower Miocene (Turritella ocoyana zone).

Fig. 3*b*. *Scutella merriami* (F. M. Anderson). Specimen 54. Lateral surface of test. × 1½.

Fig. 3*c*. *Scutella merriami* (F. M. Anderson). Specimen 54. Lower surface of test. × 1½.

Fig. 3*d*. *Scutella merriami* (F. M. Anderson). Specimen 11366, Univ. Calif. Coll. Invert. Pal. Upper surface of test. × 1½. North McKittrick district, Kern County, Calif., Univ. Calif. loc. 3073. Monterey group (Turritella ocoyana zone), Lower Miocene.

Fig. 3*e*. *Scutella merriami* (F. M. Anderson). Specimen 11367, Univ. Calif. Coll. Invert. Pal. Lateral surface of test, showing ridging of the anterior part of the abactinal surface. × 1½. Cantua Creek, Fresno County, Calif., Univ. Calif. loc. 3074. Monterey group (Turritella ocoyana zone), Lower Miocene.

Fig. 3*f*. *Scutella merriami* (F. M. Anderson). Specimen 11367. Lower surface of test. × 1½.

Fig. 4*a*. *Scutella gabbi* (Rémond). Neotype, specimen 11368, Univ. Calif. Coll. Invert. Pal. Upper surface of test, showing typical scutellid plate arrangement. Natural size. Contra Costa County, Calif. Lower part of San Pablo group, Upper Miocene.

Fig. 4*b*. *Scutella gabbi* (Rémond). Same specimen. Lateral surface of test. Natural size.


1a
1b
2a
1c
3a
3d
2b
3e
3b
4b
4a
3f
3c

EXPLANATION OF PLATE 13

Figures approximately natural size.

Fig. 1. *Scutella gabbi* (Rémond). Neotype, specimen 11001, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 2983. Basal beds of the San Pablo group, Upper Miocene.

Fig. 2*a*. *Scutella gabbi* (Rémond) (*large form*). Specimen 11002, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 1282. Basal beds of the San Pablo group, Upper Miocene.

Fig. 2*b*. *Scutella gabbi* (Rémond) (*large form*). Specimen 11369. Lower surface of test.

Fig. 3. *Scutella gabbi* (Rémond) (*notched form*). Specimen 11007, Univ. Calif. Coll. Invert Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 1478. Upper San Pablo group, Upper Miocene, occurring with *Astrodapsis tumidus* Rémond.

Fig. 4*a*. *Scutella gabbi* var. *tenuis* Kew. Holotype, specimen 11005, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif. Lower San Pablo group, Upper Miocene.

Fig. 4*b*. *Scutella gabbi* var. *tenuis* Kew. Specimen 11370, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Same locality.

Fig. 5*a*. *Astrodapsis brewerianus* (Rémond). Neotype, specimen 11016, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Walnut Creek, Contra Costa County, Calif. Briones formation (''Scutella breweriana zone''), Middle Miocene.

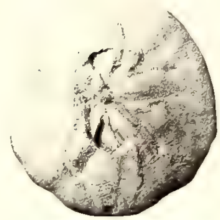
Fig. 5*b*. *Astrodapsis brewerianus* (Rémond). Specimen 11016. Lateral surface of test.

Fig. 5*c*. *Astrodapsis brewerianus* (Rémond). Specimen 11371, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Contra Costa County, Calif. Briones formation, Middle Miocene.

Fig. 6. *Astrodapsis brewerianus diabloensis* Kew, n. var. Holotype, specimen 11335, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Las Trampas Ridge, Contra Costa County, Calif., Univ. Calif. loc. 1191. Briones formation, Middle Miocene.


2a


1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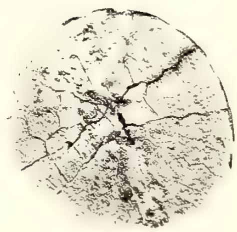
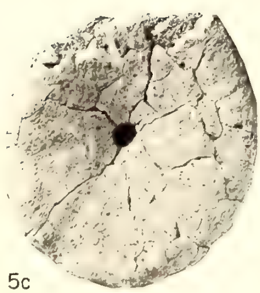
2b


4a


4b


5b


5a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6

EXPLANATION OF PLATE 14

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis cierboensis* (Kew). Cotype, specimen 10061, Univ. Calif. Coll. Invert. Pal. Upper surface of test. San Pablo Bay region, Contra Costa County, Calif., Univ. Calif. loc. 522. Lower San Pablo group, Upper Miocene.

Fig. 1*b*. *Astrodapsis cierboensis* (Kew). Specimen 10061. Lateral surface of test.

Fig. 1*c*. *Astrodapsis cierboensis* (Kew). Cotype, specimen 10062, Univ. Calif. Coll. Invert. Pal. Lower surface of test. San Pablo Bay region, Contra Costa County, Calif., Univ. Calif. loc. 526. Lower San Pablo group, Upper Miocene.

Fig. 2*a*. *Astrodapsis* (?) *pabloensis* (Kew). Holotype, specimen 10063, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 232. Lower San Pablo group, Upper Miocene.

Fig. 2*b*. *Astrodapsis* (?) *pabloensis* (Kew). Same specimen. Lateral surface of test.

Fig. 2*c*. *Astrodapsis* (?) *pabloensis* (Kew). Same specimen. Lower surface of test.

Fig. 3*a*. *Astrodapsis tumidus* Rémond. Specimen 11008, Univ. Calif. Coll. Invert. Pal. Upper surface of test. South side of Mount Diablo, Contra Costa County, Calif., Univ. Calif. loc. 482. Upper San Pablo group, Upper Miocene.

Fig. 3*b*. *Astrodapsis tumidus* Rémond. Same specimen. Lower surface of test.

Fig. 3*c*. *Astrodapsis tumidus* Rémond. Same specimen. Lateral surface of test.

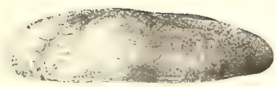
Fig. 4*a*. *Astrodapsis tumidus* Rémond (*small thick form*). Holotype, specimen 11006, Univ. Calif. Coll. Invert. Pal. Contra Costa County, Calif., Univ. Calif. loc. 56. Upper surface of test. Upper San Pablo group, Upper Miocene.

Fig. 4*b*. *Astrodapsis tumidis* Rémond (*small thick form*). Same specimen. Lateral surface of test.


1a


1c


2a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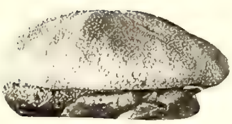
2b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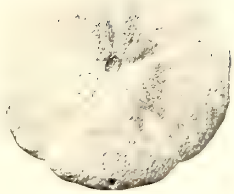
2c


4a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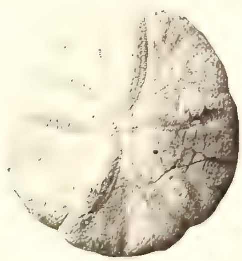
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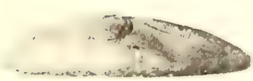
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EXPLANATION OF PLATE 15

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis major* (Kew). Cotype, specimen 11003, Univ. Calif. Coll. Invert. Pal. Upper surface of test. South side of Mount Diablo, Contra Costa County, Calif., Univ. Calif. loc. 1742. Uppermost beds of the San Pablo group, Lower Pliocene.

Fig. 1*b*. *Astrodapsis major* (Kew). Cotype, specimen 11337, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Univ. Calif. loc. 1742.

Fig. 1*c*. *Astrodapsis major* (Kew). Specimen 11003. Lateral surface of test.

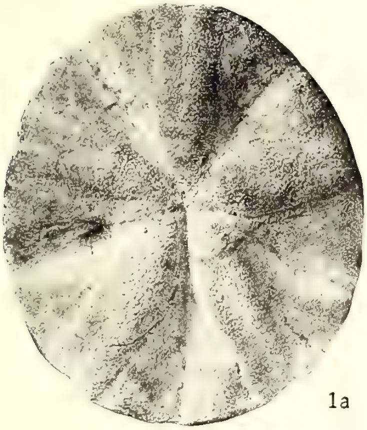
Fig. 2*a*. *Astrodapsis arnoldi peltoides* (F. M. Anderson and B. Martin). Specimen 451, Calif. Acad. Sci. Coll. Invert. Pal. Upper surface of test. Head of Zapato Chino Creek, Fresno County, Calif., Calif. Acad. Sci. loc. 293. Trophon zone, Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 2*b*. *Astrodapsis arnoldi peltoides* (F. M. Anderson and B. Martin). Specimen 451. Lateral surface of test.

Fig. 3. *Astrodapsis arnoldi peltoides* (F. M. Anderson and B. Martin). Specimen 11336, Univ. Calif. Coll. Invert. Pal. Upper surface of test of an oval-shaped specimen. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 2675. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 4*a*. *Astrodapsis altus* Kew. Holotype, specimen 10065, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 1950. Upper San Pablo group, Upper Miocene.

Fig. 4*b*. *Astrodapsis altus* Kew. Same specimen. Lateral surface of test.

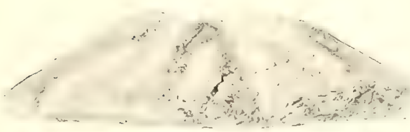


1a

1b

1c

2a



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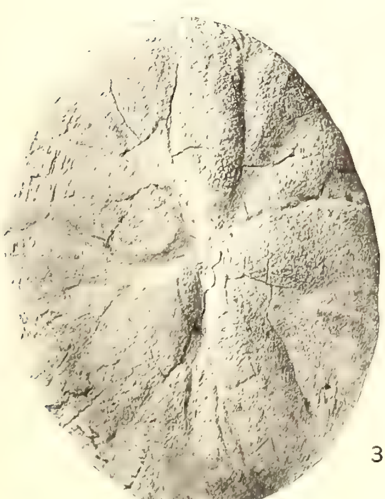

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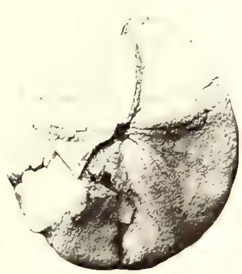


4a

4b

EXPLANATION OF PLATE 16

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis whitneyi* Rémond. Specimen 11004, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Contra Costa County, Calif., Univ. Calif. loc. 1227. Upper San Pablo group, Upper Miocene.

Fig. 1*b*. *Astrodapsis whitneyi* Rémond. Same specimen. Lateral surface of test.

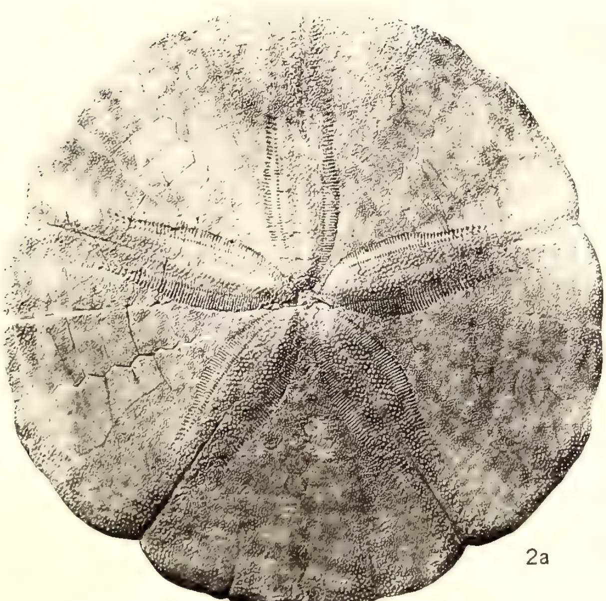
Fig. 2*a*. *Astrodapsis coalingaensis* Kew, n. sp. Holotype, specimen 11355, Univ. Calif. Coll. Invert. Pal. Upper surface of test. North of Coalinga, Fresno County, Calif., Univ. Calif. loc. 3076. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 2*b*. *Astrodapsis coalingaensis* Kew, n. sp. Same specimen. Lateral surface of test.

1a

1b

2b



2a

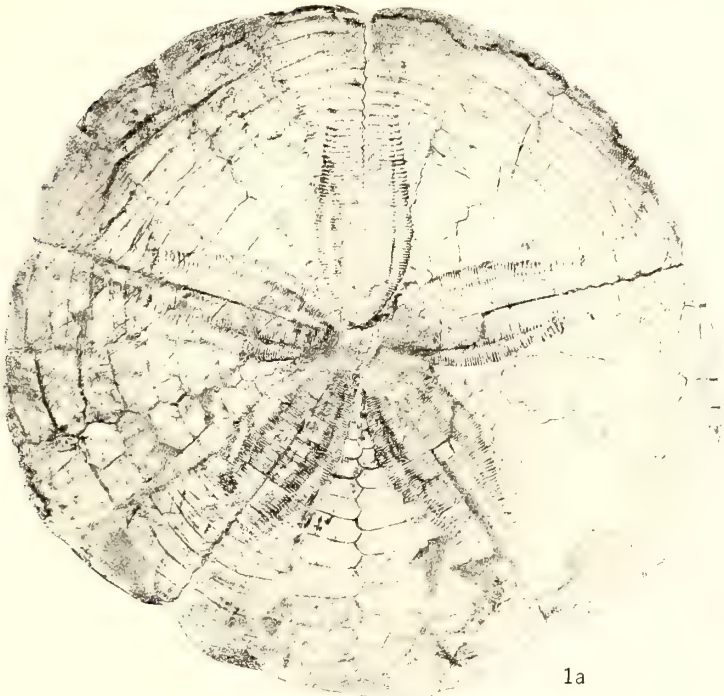
EXPLANATION OF PLATE 17

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis grandis* Kew, n. sp. Cotype, specimen 11046, Univ. Calif. Coll. Invert. Pal. Upper surface of test. North of Coalinga, Fresno County, Calif., Univ. Calif. loc. 2268. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 1*b*. *Astrodapsis grandis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 2. *Astrodapsis whitneyi* Rémond. Specimen 11036, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Contra Costa County, Calif., Univ. Calif. loc. 1227. Upper San Pablo group, Upper Miocene.



1a

1b

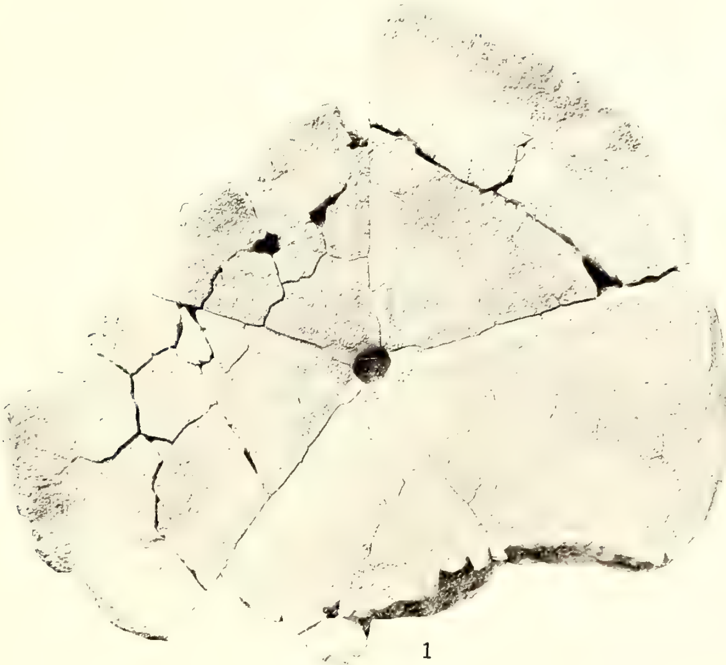
2

EXPLANATION OF PLATE 18

Figures approximately natural size.

Fig. 1. *Astrodapsis grandis* Kew, n. sp. Cotype, specimen 11047, Univ. Calif. Coll. Invert. Pal. Lower surface of test. North of Coalinga, Fresno County, Calif., Univ. Calif. loc. 2268. Upper San Pablo group (Santa Margarita formation); Upper Miocene.

Fig. 2. *Astrodapsis californicus* Kew, n. sp. Holotype, specimen 11354, Univ. Calif. Coll. Invert. Pal. Upper surface of test. North of Coalinga, Fresno County, Calif., Univ. Calif. loc. 3077, Upper San Pablo group (Santa Margarita), Upper Miocene.



1

2

EXPLANATION OF PLATE 19

Figures approximately natural size.

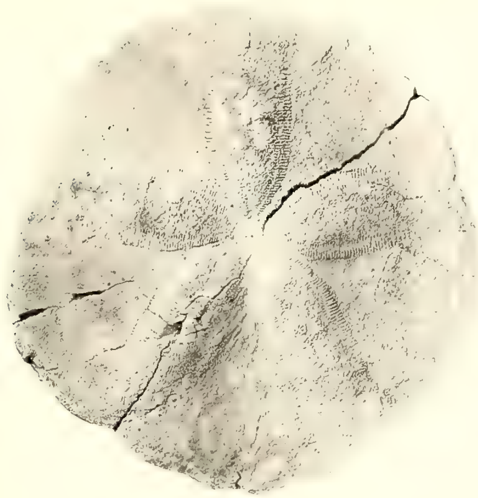
Fig. 1*a*. *Astrodapsis cuyamanus* Kew, n. sp. Holotype, specimen 11045, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Cuyama Valley, Santa Barbara County, Calif., Univ. Calif. loc. 3078. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 1*b*. *Astrodapsis cuyamanus* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 2*a*. *Astrodapsis antiselli* Conrad. Specimen 11372, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Salinas Valley, Monterey County, Calif., Univ. Calif. loc. 3079. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 2*b*. *Astrodapsis antiselli* Conrad. Specimen 11373, Univ. Calif. Coll Invert. Pal. Lower surface of test. Univ. Calif. loc. 3079.

Fig. 2*c*. *Astrodapsis antiselli* Conrad. Specimen 11373. Lateral surface of test.



1a

1b

2a

2b

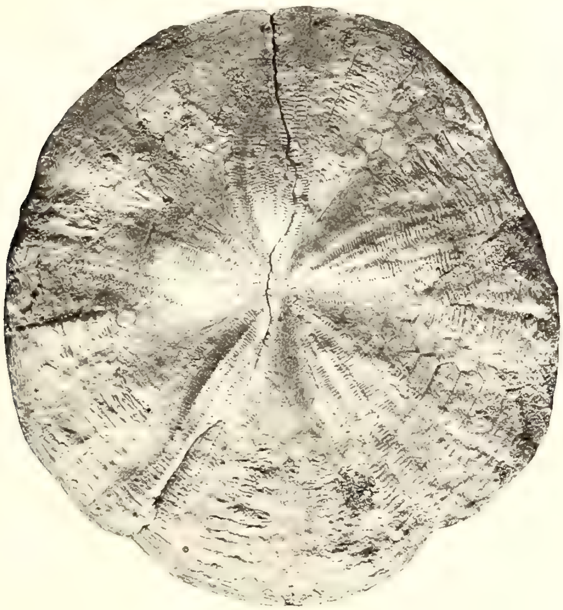
2c

EXPLANATION OF PLATE 20

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis jacalitosensis* Arnold. Holotype, specimen 165610, U. S. Nat. Mus. Upper surface of test. Coalinga district, Fresno County, Calif. Lower Etchegoin (Jacalitos) formation, Lower Pliocene. Photographed by U. S. Geological Survey.

Fig. 1*b*. *Astrodapsis jacalitosensis* Arnold. Specimen 11037, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 2688.



1a

1b

EXPLANATION OF PLATE 21

Fig. 1*a*. *Astrodapsis ornatus* Kew, n. sp. Cotype, specimen 11374, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Natural size. San Juan River district, San Luis Obispo County, Calif., Univ. Calif. loc. 2721. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 1*b*. *Astrodapsis ornatus* Kew, n. sp. Cotype, specimen 11375, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Natural size. Same locality.

Fig. 1*c*. *Astrodapsis ornatus* Kew, n. sp. Specimen 11375. Upper surface of test. Natural size.

Fig. 1*d*. *Astrodapsis ornatus* Kew, n. sp. Specimen 11375. Lower surface of test. Natural size.

Fig. 2. *Astrodapsis scutelliformis* Kew, n. sp. Holotype, specimen 11048, Univ. Calif. Coll. Invert. Pal. Upper surface of test. × 2. Univ. Calif. loc. 2354.

Fig. 3*a*. *Astrodapsis arnoldi arnoldi* (Pack). Holotype, specimen 11030, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Natural size. Salinas Valley, Monterey County, Calif. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

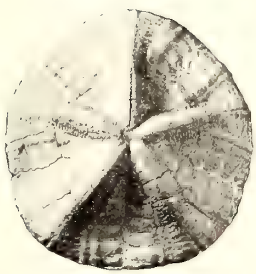
Fig. 3*b*. *Astrodapsis arnoldi arnoldi* (Pack). Same specimen. Lower surface of test. Natural size.

Fig. 3*c*. *Astrodapsis arnoldi arnoldi* (Pack). Same specimen. Lateral surface of test. Natural size.


1a


2


1b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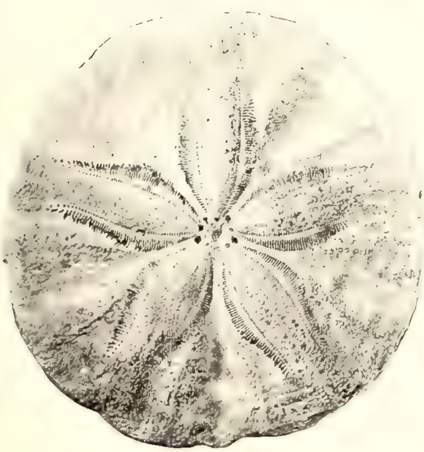
1d


3a


3b


3c

EXPLANATION OF PLATE 22

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis margaritanus* Kew, n. sp. Cotype, specimen 11023, Univ. Calif. Coll. Invert. Pal. San Luis Obispo County, Calif., Univ. Calif. loc. 1697. Upper San Pablo group (Santa Margarita formation), Upper Miocene. Upper surface of test.

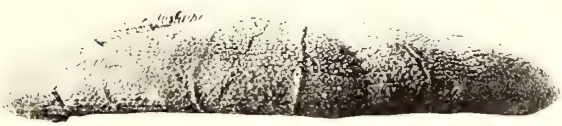
Fig. 1*b*. *Astrodapsis margaritanus* Kew, n. sp. Specimen 11035, Univ. Calif. Coll. Invert. Pal. Upper surface of an elongate specimen. San Luis Obispo County, Calif., Univ. Calif. loc. 1707. Upper San Pablo group (Santa Margarita formation), Upper Miocene.

Fig. 2*a*. *Astrodapsis arnoldi spatiosus* Kew, n. subsp. Holotype, specimen 11041, Univ. Calif. Coll. Invert. Pal. Upper surface of test. West side Salinas Valley, Monterey County, Calif. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 2*b*. *Astrodapsis arnoldi spatiosus* Kew, n. subsp. Same specimen. Lateral surface of test.


1a


1b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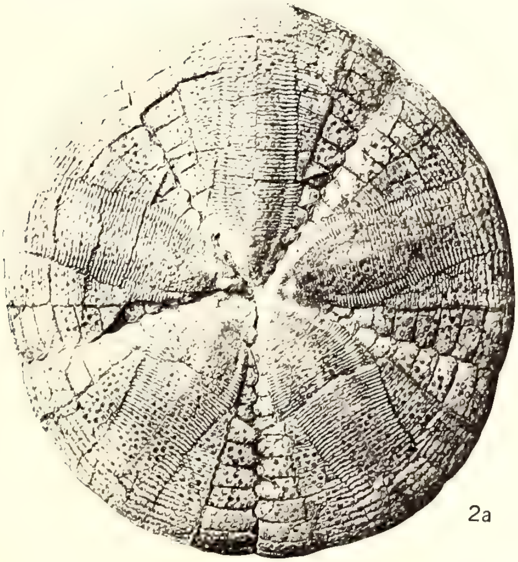

2a

EXPLANATION OF PLATE 23

Figures approximately natural size.

Fig. 1. *Astrodapsis arnoldi crassus* Kew, n. subsp. Specimen 11376, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Pence Enrico Cañon, Monterey County, Calif., Univ. Calif. loc. 2727. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 2*a*. *Astrodapsis arnoldi depressus* Kew, n. var. Holotype, specimen 11038, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 2973. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

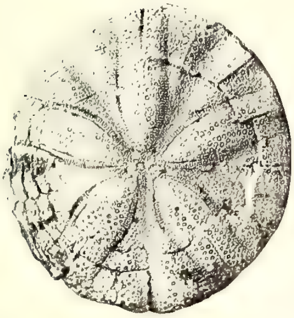
Fig. 2*b*. *Astrodapsis arnoldi depressus* Kew, n. var. Same specimen. Lower surface of test.

Fig. 2*c*. *Astrodapsis arnoldi depressus* Kew, n. var. Same specimen. Lateral surface of test.

Fig. 3*a*. *Astrodapsis arnoldi fresnoensis* Kew, n. var. Holotype, specimen 11032, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 2973. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 3*b*. *Astrodapsis arnoldi fresnoensis* Kew, n. var. Same specimen. Lower surface of test.

Fig. 3*c*. *Astrodapsis arnoldi fresnoensis* Kew, n. var. Same specimen. Lateral surface of test.



1

2a

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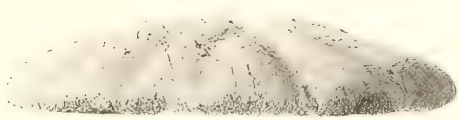
3a



2c

3b

3c

EXPLANATION OF PLATE 24

Figures approximately natural size.

Fig. 1*a*. *Astrodapsis arnoldi crassus* Kew, n. subsp. Holotype, specimen 11350, Univ. Calif. Coll. Invert. Pal. Upper surface of test. South of Pancho Rico Creek, Monterey County, Calif., Univ. Calif. loc. 3127. Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 1*b*. *Astrodapsis arnoldi crassus* Kew, n. subsp. Same specimen. Lateral surface of test.

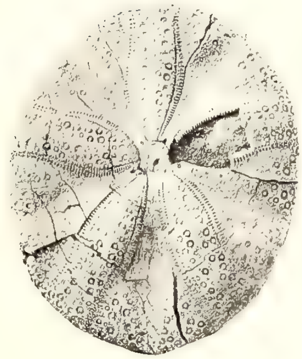
Fig. 1*c*. *Astrodapsis arnoldi crassus* Kew, n. subsp. Same specimen. Lower surface of test.

Fig. 2*a*. *Astrodapsis fernandoensis* Pack. Cotype, specimen 11042, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Elsmere Cañon, Los Angeles County, Calif., Univ. Calif. loc. 1602. Basal beds of Fernando formation, Lower Pliocene.

Fig. 2*b*. *Astrodapsis fernandoensis* Pack. Specimen 11042. Lateral surface of test.

Fig. 2*c*. *Astrodapsis fernandoensis* Pack. Cotype, specimen 11377, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Elsmere Cañon, Los Angeles County, Calif. Basal beds of Fernando formation, Lower Pliocene.


1a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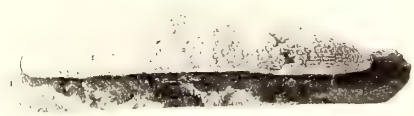
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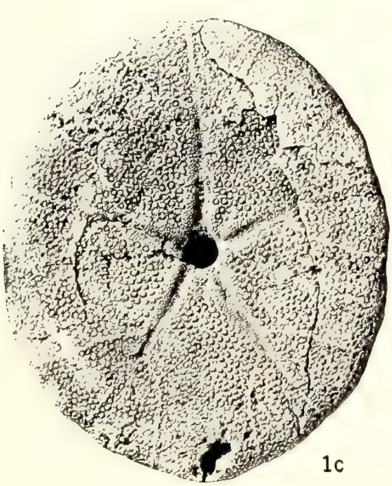
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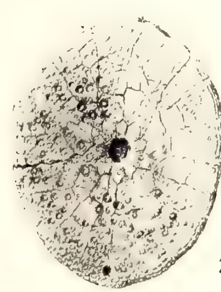

2c

EXPLANATION OF PLATE 25

Figures approximately natural size.

Fig. 1*a*. *Dendraster jacalitosensis* Kew, n. sp. Holotype, specimen 11034 Univ. Calif. Coll. Invert. Pal. Upper surface of test. North side of Reef Ridge, Tar Cañon, Fresno County, Calif., Univ. Calif. loc. 2954. Lower beds of Lower Etchegoin (Jacalitos) formation, Lower Pliocene.

Fig. 1*b*. *Dendraster jacalitosensis* Kew, n. sp. Same specimen. Lateral surface of test.

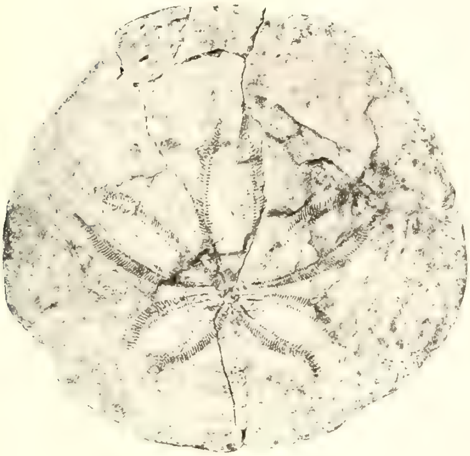
Fig. 2*a*. *Dendraster gibbsii* (Rémond). Specimen 11021, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif. Etchegoin formation, Pliocene.

Fig. 2*b*. *Dendraster gibbsii* (Rémond). Specimen 11380, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Coalinga district, Calif. Etchegoin formation, Pliocene.

Fig. 2*c*. *Dendraster gibbsii* (Rémond). Specimen 11021, Univ. Calif. Coll. Invert. Pal. Lateral surface of test.

Fig. 3*a*. *Dendraster gibbsii humilis* Kew, n. var. Holotype, specimen 11379, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 1772. Upper Etchegoin formation, Middle Pliocene.

Fig. 3*b*. *Dendraster gibbsii humilis* Kew, n. var. Same specimen. Lateral surface of test.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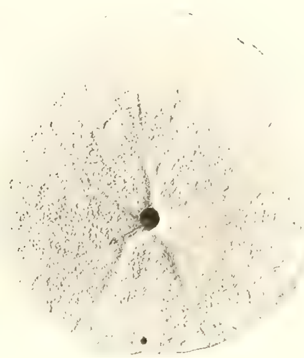
2a


1b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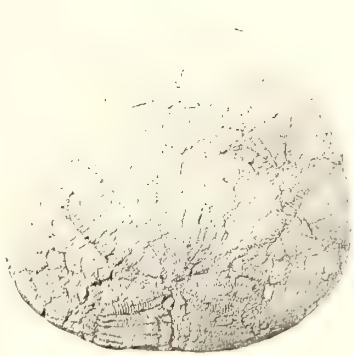
2c


3b


3a

EXPLANATION OF PLATE 26

Figures approximately natural size.

Fig. 1*a*. *Dendraster hesperis* Kew, n. sp. Holotype, specimen 11381, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 3004. Pecten coalingaensis zone, Upper Etchegoin formation, Middle Pliocene.

Fig. 1*b*. *Dendraster hesperis* Kew, n. sp. Specimen 11381. Lateral surface of test.

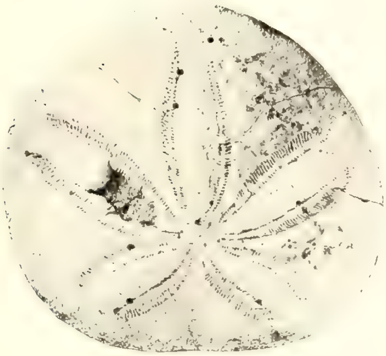
Fig. 1*c*. *Dendraster hesperis* Kew, n. sp. Specimen 11382, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 3003. Pecten coalingaensis zone, Upper Etchegoin, Middle Pliocene.

Fig. 2*a*. *Dendraster hesperis gibbosus* Kew, n. var. Holotype, specimen 11022, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 525. Pecten coalingaensis zone, Upper Etchegoin, Middle Pliocene.

Fig. 2*b*. *Dendraster hesperis gibbosus* Kew, n. var. Same specimen. Lateral surface of test.

Fig. 3*a*. *Scutaster andersoni* Pack. Lectotype, specimen in U. S. Nat. Mus. Upper surface of test. Northeast of Antimony Peak, Fresno County, Calif. Upper Oligocene.

Fig. 3*b*. *Scutaster andersoni* Pack. Same specimen. Lateral surface of test.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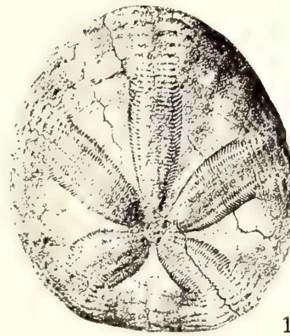
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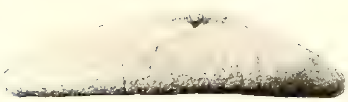
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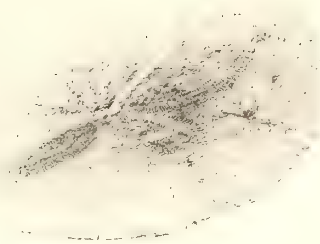
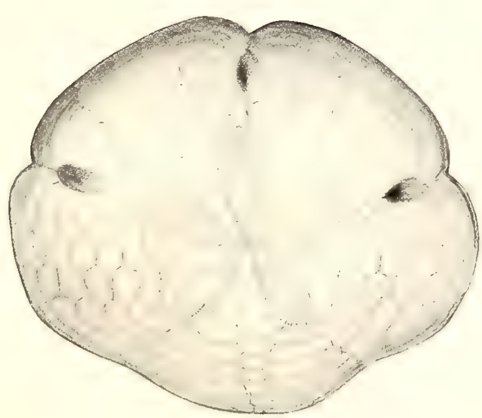

2a


2b


3b


3a

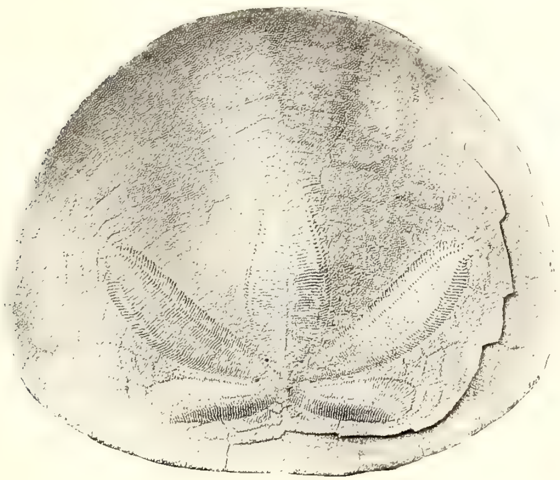
EXPLANATION OF PLATE 27

Figures approximately natural size.

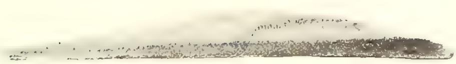
Fig. 1*a*. *Dendraster ashleyi* (Arnold). Specimen 11043, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Purisima Hills, Santa Barbara County, Calif., Univ. Calif. loc. 3130. Upper Fernando formation, Upper Pliocene.

Fig. 1*b*. *Dendraster ashleyi* (Arnold). Same specimen. Lateral surface of test.

Fig. 1*c*. *Dendraster ashleyi* (Arnold). Same specimen. Lower surface of test.



1a



1b

1c

EXPLANATION OF PLATE 28

Figures approximately natural size.

Fig. 1*a*. *Dendraster coalingaensis* Twitchell. Specimen 11383, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif., Univ. Calif. loc. 2108. Upper Etchegoin formation, Middle Pliocene.

Fig. 1*b*. *Dendraster coalingaensis* Twitchell. Same specimen. Lower surface of test.

Fig. 1*c*. *Dendraster coalingaensis* Twitchell. Same specimen. Lateral surface of test.

Fig. 2*a*. *Dendraster arnoldi* Twitchell. Specimen 11384, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Sargent Oil Field, Santa Cruz County, Calif., Univ. Calif. loc. 3129. Upper Etchegoin formation, Middle Pliocene.

Fig. 2*b*. *Dendraster arnoldi* Twitchell. Specimen 165701, U. S. Nat. Mus. Lower surface of test. Zapato Creek, Coalinga district, Fresno County, Calif. Upper Etchegoin formation, Middle Pliocene.

Fig. 2*c*. *Dendraster arnoldi* Twitchell. Specimen 11384. Lateral surface of test.

Fig. 3*a*. *Dendraster perrini* (Weaver). Specimen 11018, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Coalinga district, Fresno County, Calif. Upper Etchegoin formation, Middle Pliocene.

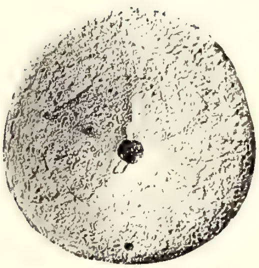
Fig. 3*b*. *Dendraster perrini* (Weaver). Same specimen. Lower surface of test.

Fig. 3*c*. *Dendraster perrini* (Weaver). Same specimen. Lateral surface of test.

1a

2b

2a



1b

1c

2c

3c

3a

3b

EXPLANATION OF PLATE 29

Figures approximately natural size.

Fig. 1*a*. *Dendraster diegoensis venturaensis* Kew, n. subsp. Holotype, specimen 11351, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Santa Barbara County, Calif. Upper Fernando formation, Upper Pliocene.

Fig. 1*b*. *Dendraster diegoensis venturaensis* Kew, n. subsp. Same specimen. Lateral surface of test.

Fig. 2. *Dendraster diegoensis diegoensis* Kew, n. subsp. Holotype, specimen 12257, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Pacific Beach, San Diego County, Calif. San Diego formation, Upper Pliocene.

1a

1b

2

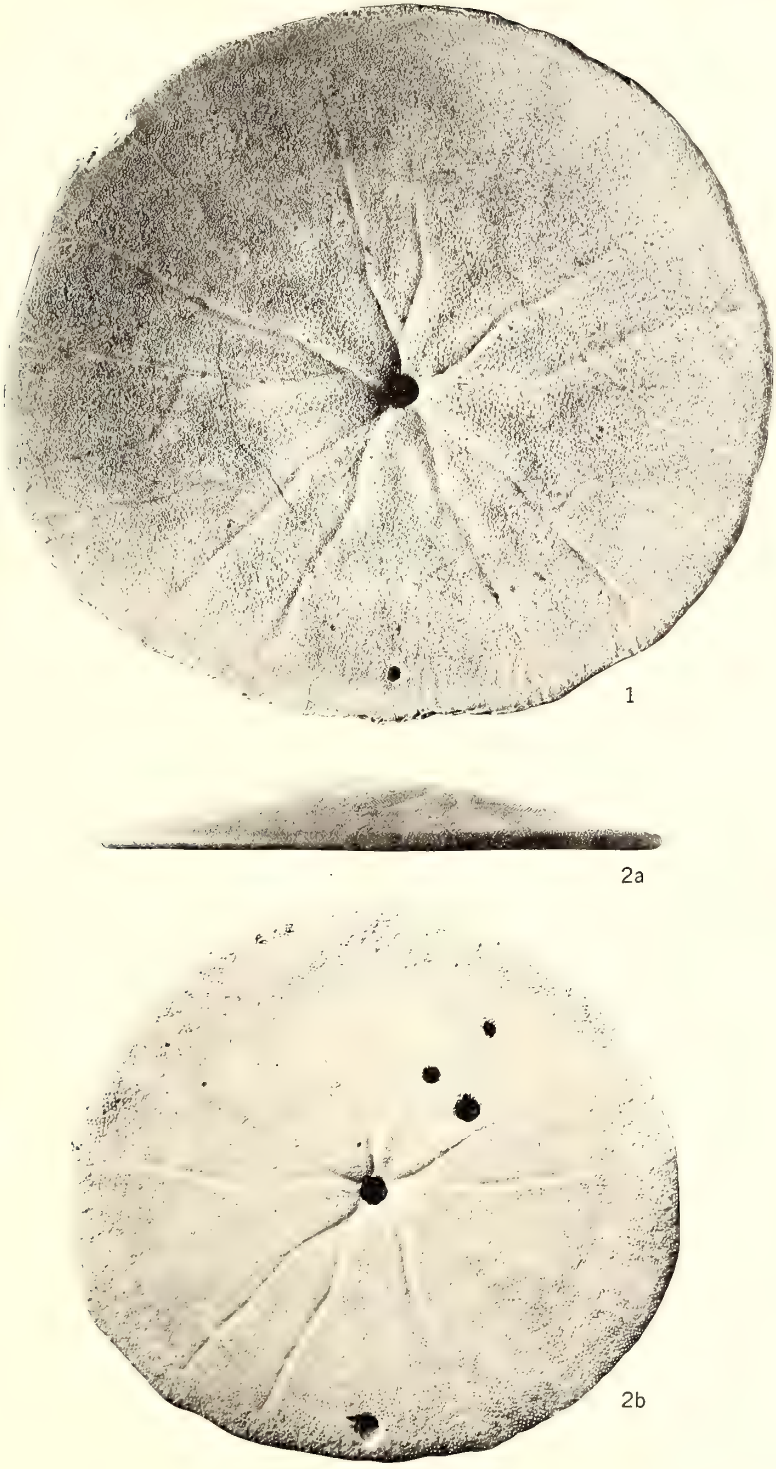
EXPLANATION OF PLATE 30

Figures approximately natural size.

Fig. 1. *Dendraster diegoensis venturaensis* Kew, n. subsp. Holotype, specimen 11351, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Santa Barbara County, Calif. Upper Fernando formation, Upper Pliocene.

Fig. 2*a*. *Dendraster diegoensis diegoensis* Kew, n. subsp. Holotype, specimen 12257, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Pacific Beach, San Diego County, Calif. San Diego formation, Upper Pliocene.

Fig. 2*b*. *Dendraster diegoensis diegoensis* Kew, n. subsp. Same specimen. Lower surface of test.



1

2a

2b

EXPLANATION OF PLATE 31

Figures approximately natural size.

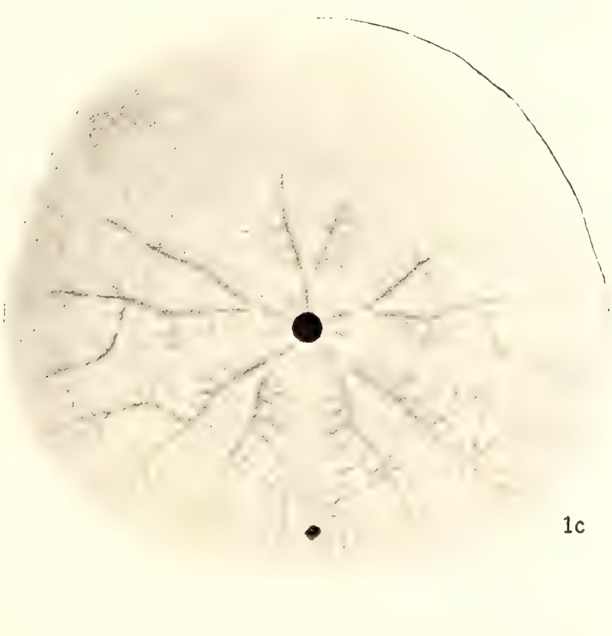
Fig. 1*a*. *Dendraster excentricus* (Eschscholtz). Specimen 12163, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Recent.

Fig. 1*b*. *Dendraster excentricus* (Eschscholtz). Same specimen. Lateral surface of test. Recent.

Fig. 1*c*. *Dendraster excentricus* (Eschscholtz). Same specimen. Lower surface of test. Recent.

1a

1b



1c

EXPLANATION OF PLATE 32

Figures approximately natural size.

Fig. 1. *Dendraster excentricus* (Eschscholtz). Specimen 12164, Univ. Calif. Coll. Invert. Pal. Upper surface of test, showing variation in petals. Recent.

Fig. 2. *Dendraster excentricus* (Eschscholtz). Specimen 12165, Univ. Calif. Coll. Invert. Pal. Upper surface of test, showing variation in petals. Recent.

1

2

EXPLANATION OF PLATE 33

Figures approximately natural size.

Fig. 1*a*. *Dendraster pacificus* Kew, n. sp. Cotype, specimen 448, Calif. Acad. Sci. Coll. Pal. Upper surface of test. Pacific Beach, San Diego County, Calif. San Diego formation, Upper Pliocene.

Fig. 1*b*. *Dendraster pacificus* Kew, n. sp. Specimen 448. Lower surface of test.

Fig. 1*c*. *Dendraster pacificus* Kew, n. sp. Cotype specimen 11340, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Cedros Island, Lower California, Upper Pliocene (?).

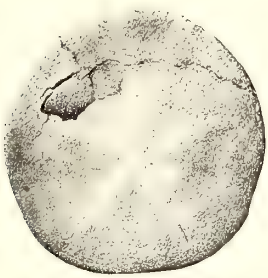
Fig. 2*a*. *Dendraster* (*Calaster*) *oregonensis* (W. B. Clark). Specimen 449, Calif. Acad. Sci. Coll. Pal. Upper surface of test. Fossil Point, Coos Bay, Oregon. Merced formation, Upper Pliocene.

Fig. 2*b*. *Dendraster* (*Calaster*) *oregonensis* (W. B. Clark). Specimen 450, Calif. Acad. Sci. Coll. Pal. Lower surface of test. Same locality.

Fig. 3*a*. *Dendraster* (*Calaster*) *oregonensis gibbosus* Kew, n. var. Cotype, specimen 11385, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Near Shively, Humboldt County, Calif., Univ. Calif. loc. 1881. Wildcat series, Upper Pliocene.

Fig. 3*b*. *Dendraster* (*Calaster*) *oregonensis gibbosus* Kew, n. var. Cotype, specimen 11386, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Same locality.

Fig. 3*c*. *Dendraster* (*Calaster*) *oregonensis gibbosus* Kew, n. var. Specimen 11386. Lateral surface of test.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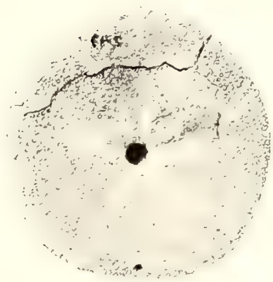
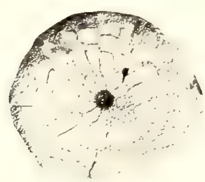

1b


1c


2a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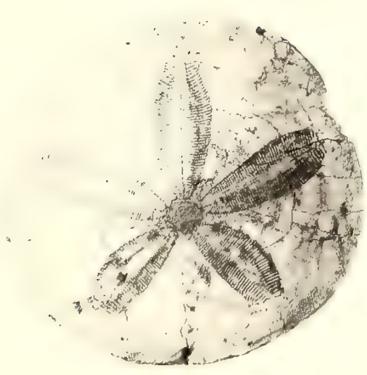
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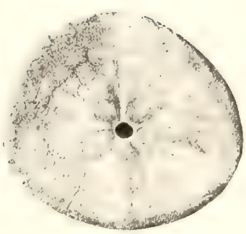
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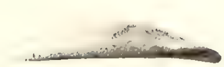

3c

EXPLANATION OF PLATE 34

Figures approximately natural size.

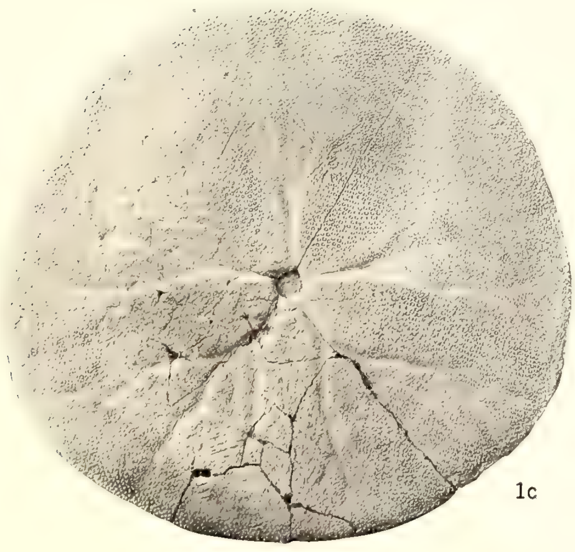
Fig. 1*a*. *Dendraster* (*Calaster*) *oregonensis major* Kew, n. var. Cotype, specimen 11044, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Eel River, Humboldt County, Calif., Univ. Calif. loc. 1876. Wildcat series, Upper Pliocene.

Fig. 1*b*. *Dendraster* (*Calaster*) *oregonensis major* Kew, n. var. Cotype, specimen 11352, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Eel River, Humboldt County, Calif., Univ. Calif. loc. 71. Wildcat series, Upper Pliocene.

Fig. 1*c*. *Dendraster* (*Calaster*) *oregonensis major* Kew, n. var. Specimen 11352. Lower surface of test.

1a

1b



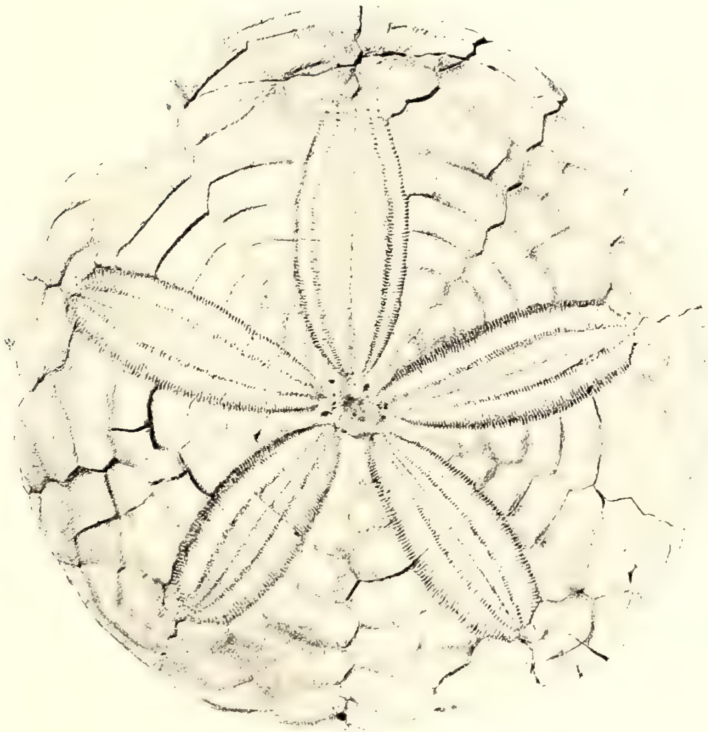
1c

EXPLANATION OF PLATE 35

Figures approximately natural size.

Fig. 1*a*. *Dendraster* (*Calaster*) *interlineatus* (Stimpson). Neotype, specimen 11353, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Seven mile Beach, San Francisco Peninsula, Calif., Univ. Calif. loc. 1726. Lower Merced formation, Upper Pliocene.

Fig. 1*b*. *Dendraster* (*Calaster*) *interlineatus* (Stimpson). Same specimen. Lateral surface of test.



1a

1b

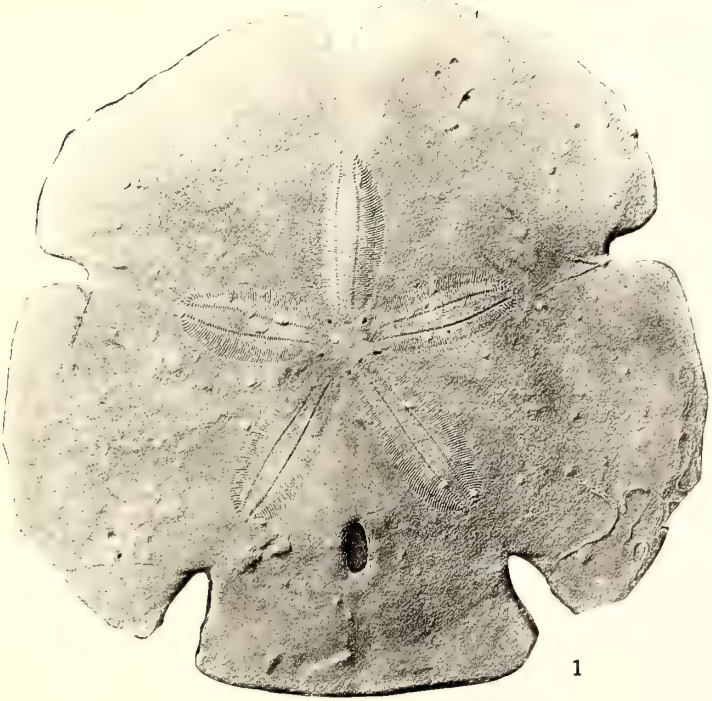
EXPLANATION OF PLATE 36

Figures approximately natural size.

Fig. 1. *Encope tenuis* Kew. Cotype, specimen 10050, Univ. Calif. Coll. Invert Pal. Upper surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower division of Carrizo Creek beds, Pliocene.

Fig. 2*a*. *Dendraster ashleyi ynezensis* Kew, n. var. Holotype, specimen 11334, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Redrock Cañon, Santa Ynez River District, Santa Barbara County, Calif., Univ. Calif. loc. 3128. Upper part of Fernando formation, Upper Pliocene.

Fig. 2*b*. *Dendraster ashleyi ynezensis* Kew, n. var. Specimen 11334, Univ. Calif. Coll. Invert. Pal. Lateral surface of test. Redrock Cañon, Santa Ynez River District, Santa Barbara County, Calif., Univ. Calif. loc. 2259. Upper part of Fernando formation, Upper Pliocene.



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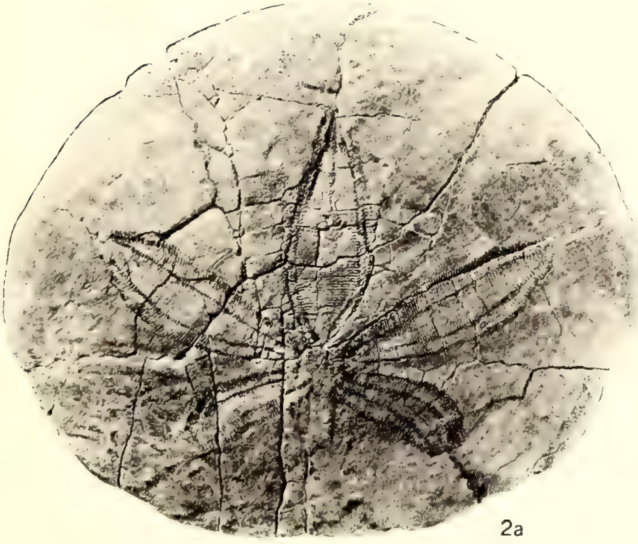


2a

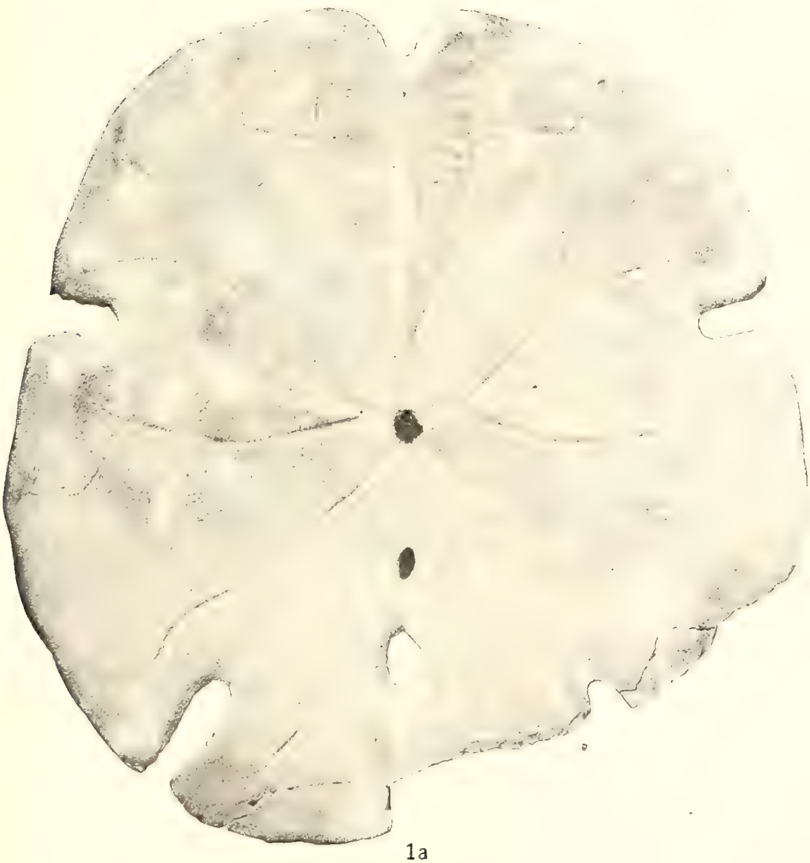
2b

EXPLANATION OF PLATE 37

Figures approximately natural size.

Fig. 1*a*. *Encope tenuis* Kew. Cotype, specimen 10051, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Coyote Mountain, Imperial County, Calif., Univ. Calif. loc. 2064. Lower Division of Carrizo Creek beds, Pliocene.

Fig. 1*b*. *Encope tenuis* Kew. Specimen 10050. Lateral surface of test.



1a

1b

EXPLANATION OF PLATE 38

Figures approximately natural size.

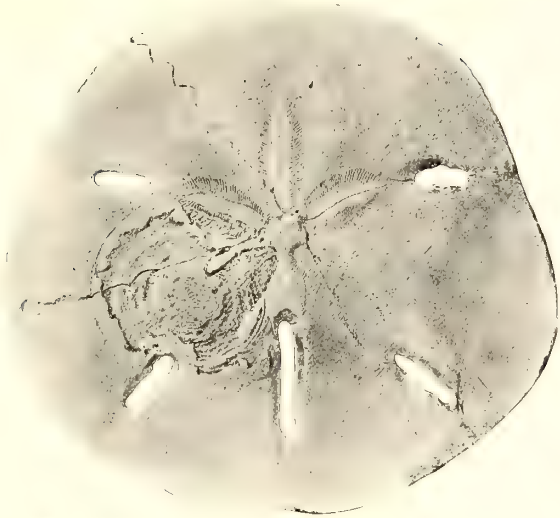
Fig. 1*a*. *Mellita longifissa* Michelin. Specimen 11025, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Newport Beach, Orange County, Calif. Upper San Pedro formation, Pleistocene.

Fig. 1*b*. *Mellita longifissa* Michelin. Same specimen. Lateral surface of test.

Fig. 1*c*. *Mellita longifissa* Michelin. Same specimen. Lower surface of test.

Fig. 1*d*. *Mellita longifissa* Michelin. Same specimen. One of the jaws seen from the lower side.

Fig. 1*e*. *Mellita longifissa* Michelin. Same specimen. One of the jaws seen from the upper side.



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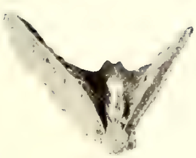
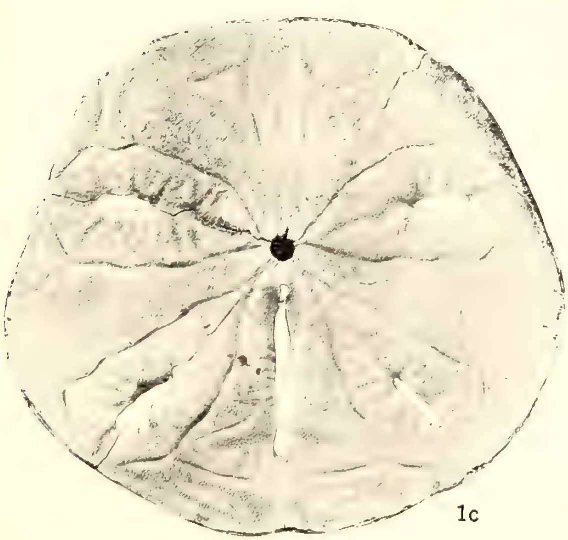


1d

1e

1b



1c

EXPLANATION OF PLATE 39

Figures approximately natural size.

Fig. 1*a*. *Cassidulus* (*Rhynchopygus*) *californicus* (F. M. Anderson). Neotype, specimen 11348, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Salt Creek, north of Coalinga, Fresno County, Calif., Univ. Calif. loc. 3131. Tejon formation (Avenal sands), Upper Eocene.

Fig. 1*b*. *Cassidulus* (*Rhynchopygus*) *californicus* (F. M. Anderson). Same specimen. Lower surface of test.

Fig. 1*c*. *Cassidulus* (*Rhynchopygus*) *californicus* (F. M. Anderson). Same specimen. Lateral surface of test.

Fig. 1*d*. *Cassidulus* (*Rhynchopygus*) *californicus* (F. M. Anderson). Same specimen. Posterior surface of test.

Fig. 2*a*. *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew, n. sp. Holotype, specimen 11345, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Oso Cañon, Santa Ynez River district, Santa Barbara County, Calif., Univ. Calif. loc. 3132. Vaqueros formation, Lower Miocene.

Fig. 2*b*. *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 2*c*. *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 2*d*. *Cassidulus* (*Rhynchopygus*) *ynezensis* Kew, n. sp. Same specimen. Posterior surface of test.

Fig. 3*a*. *Cassidulus* (*Rhynchopygus*) *ellipticus* Kew, n. sp. Cotype, specimen 11346, enlarged approximately one-third natural size, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Oso Cañon, Santa Ynez River district, Santa Barbara County, Calif., Univ. Calif. loc. 3132. Vaqueros formation, Lower Miocene.

Fig. 3*b*. *Cassidulus* (*Rhynchopygus*) *ellipticus* Kew, n. sp. Cotype specimen 11347, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Univ. Calif. loc. 3132.

Fig. 3*c*. *Cassidulus* (*Rhynchopygus*) *ellipticus* Kew, n. sp. Specimen 11346. Lateral surface of test.

Fig. 3*d*. *Cassidulus* (*Rhynchopygus*) *ellipticus* Kew, n. sp. Specimen 11346. Posterior surface of test.

Fig. 4*a*. *Cassidulus* (*Rhynchopygus*) *mexicanus* Kew, n. sp. Holotype, specimen 11357, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Approximately reduced one half. San Ysidro, Lower California. Pliocene (?).

Fig. 4*b*. *Cassidulus* (*Rhynchopygus*) *mexicanus* Kew, n. sp. Same specimen. Lateral surface of test. $\times \frac{1}{2}$.

Fig. 4*c*. *Cassidulus* (*Rhynchopygus*) *mexicanus* Kew, n. sp. Same specimen. Posterior surface of test. $\times \frac{1}{2}$.

1a 1b 2a

1c 2b 2c

1d 4a 2d

3a 3c

4b

3b 4c 3d

EXPLANATION OF PLATE 40

Figures approximately natural size.

Fig. 1*a*. *Catopygus(?) cajonensis* Kew, n. sp. Holotype, specimen 11344, Univ. Calif. Coll. Invert. Pal. Upper surface of a poorly preserved specimen. Big Rock Creek, Los Angeles County, Calif., Univ. Calif. loc. 2249. Martinez group, Lower Eocene.

Fig. 1*b*. *Catopygus(?) cajonensis* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 1*c*. *Catopygus(?) cajonensis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 2*a*. *Catopygus(?) californicus* Kew, n. sp. Holotype, specimen 11014, Univ. Calif. Coll. Invert. Pal. Upper surface of a poorly preserved cast. Contra Costa Hills, Contra Costa County, Calif., Univ. Calif. loc. 3140. Chico formation, Upper Cretaceous.

Fig. 2*b*. *Catopygus(?) californicus* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 2*c*. *Catopygus(?) californicus* Kew, n. sp. Same specimen. Posterior surface of test.

Fig. 2*d*. *Catopygus(?) californicus* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 3*a*. *Epiaster depressus* Kew, n. sp. Cotype, specimen 11011. Univ. Calif. Coll. Invert. Pal. Upper surface of test. Northern California. Chico formation, Upper Cretaceous.

Fig. 3*b*. *Epiaster depressus* Kew, n. sp. Specimen 11011. Lateral surface of test.

Fig. 3*c*. *Epiaster depressus* Kew, n. sp. Cotype, specimen 11339, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Northern California. Chico formation, Upper Cretaceous.

Fig. 3*d*. *Epiaster depressus* Kew, n. sp. Specimen 11339. Lower surface of test.

Fig. 4*a*. *Hemiaster californicus* W. B. Clark. Specimen 11013, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Santa Ana Mountains, Orange County, Calif., Univ. Calif. loc. 2139. Chico formation, Upper Cretaceous.

Fig. 4*b*. *Hemiaster californicus* W. B. Clark. Same specimen. Lower surface of test.

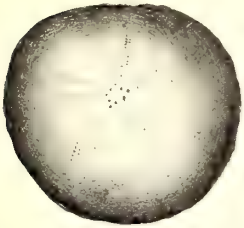
Fig. 4*c*. *Hemiaster californicus* W. B. Clark. Same specimen. Lateral surface of test.

Fig. 5*a*. *Hemiaster alamedensis* Kew, n. sp. Holotype, specimen 11009, Univ. Calif. Coll. Invert. Pal. Contra Costa Hills, Contra Costa County, Calif., Univ. Calif. loc. 3140. Chico formation, Upper Cretaceous, and Knoxville, Lower Cretaceous.

Fig. 5*b*. *Hemiaster alamedensis* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 5*c*. *Hemiaster alamedensis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 5*d*. *Hemiaster alamedensis* Kew, n. sp. Same specimen. Posterior surface of test.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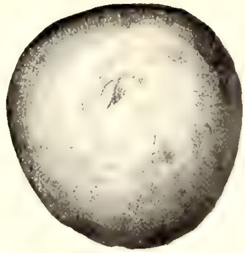
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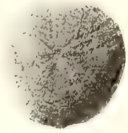
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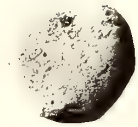
2b


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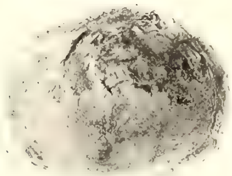
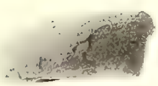

1c


2c


2d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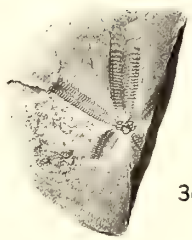
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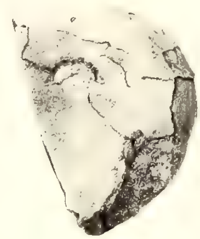
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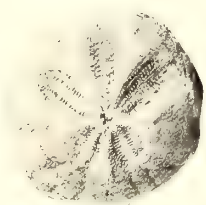
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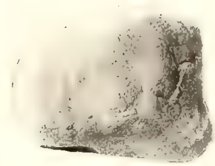
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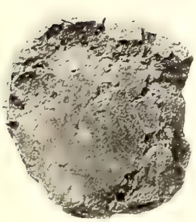
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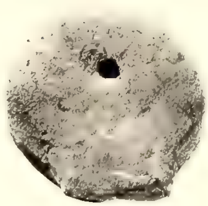
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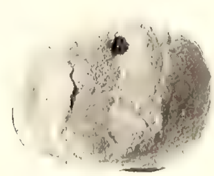
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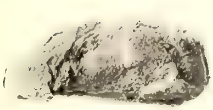

4c

EXPLANATION OF PLATE 41

Figures approximately natural size.

Fig. 1*a*. *Hemiaster cholamensis* Kew, n. sp. Cotype, specimen 11338, Univ. Calif. Coll. Invert. Pal. Upper surface of test. East side of Cholame Valley, Monterey County, Calif., Univ. Calif. loc. 3141. Cretaceous (?).

Fig. 1*b*. *Hemiaster cholamensis* Kew, n. sp. Cotype, specimen 11343, Univ. Calif. Coll. Invert. Pal. Lower surface of test. Univ. Calif. loc. 3141.

Fig. 1*c*. *Hemiaster cholamensis* Kew, n. sp. Specimen 11338. Posterior surface of test.

Fig. 1*d*. *Hemiaster cholamensis* Kew, n. sp. Specimen 11338. Lateral surface of test.

Fig. 2*a*. *Hemiaster oregonensis* Kew, n. sp. Cotype, specimen 11040, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Jackson County, Oregon, Univ. Calif. loc. 3142. Cretaceous.

Fig. 2*b*. *Hemiaster oregonensis* Kew, n. sp. Cotype, specimen 11039, Univ. Calif. Coll. Invert. Pal. Upper surface of the test of a crushed specimen. Univ. Calif. loc. 3142. Cretaceous.

Fig. 2*c*. *Hemiaster oregonensis* Kew, n. sp. Specimen 11039. Lower surface of test.

Fig. 2*d*. *Hemiaster oregonensis* Kew, n. sp. Specimen 11040. Lateral surface of test.

Fig. 3*a*. *Schizaster lecontei* Merriam. Specimen 11341, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Near Vine Hill Station, Contra Costa County, Calif. Martinez group, Lower Eocene.

Fig. 3*b*. *Schizaster lecontei* Merriam. Same specimen. Lower surface of test.

Fig. 3*c*. *Schizaster lecontei* Merriam. Same specimen. Lateral surface of test.

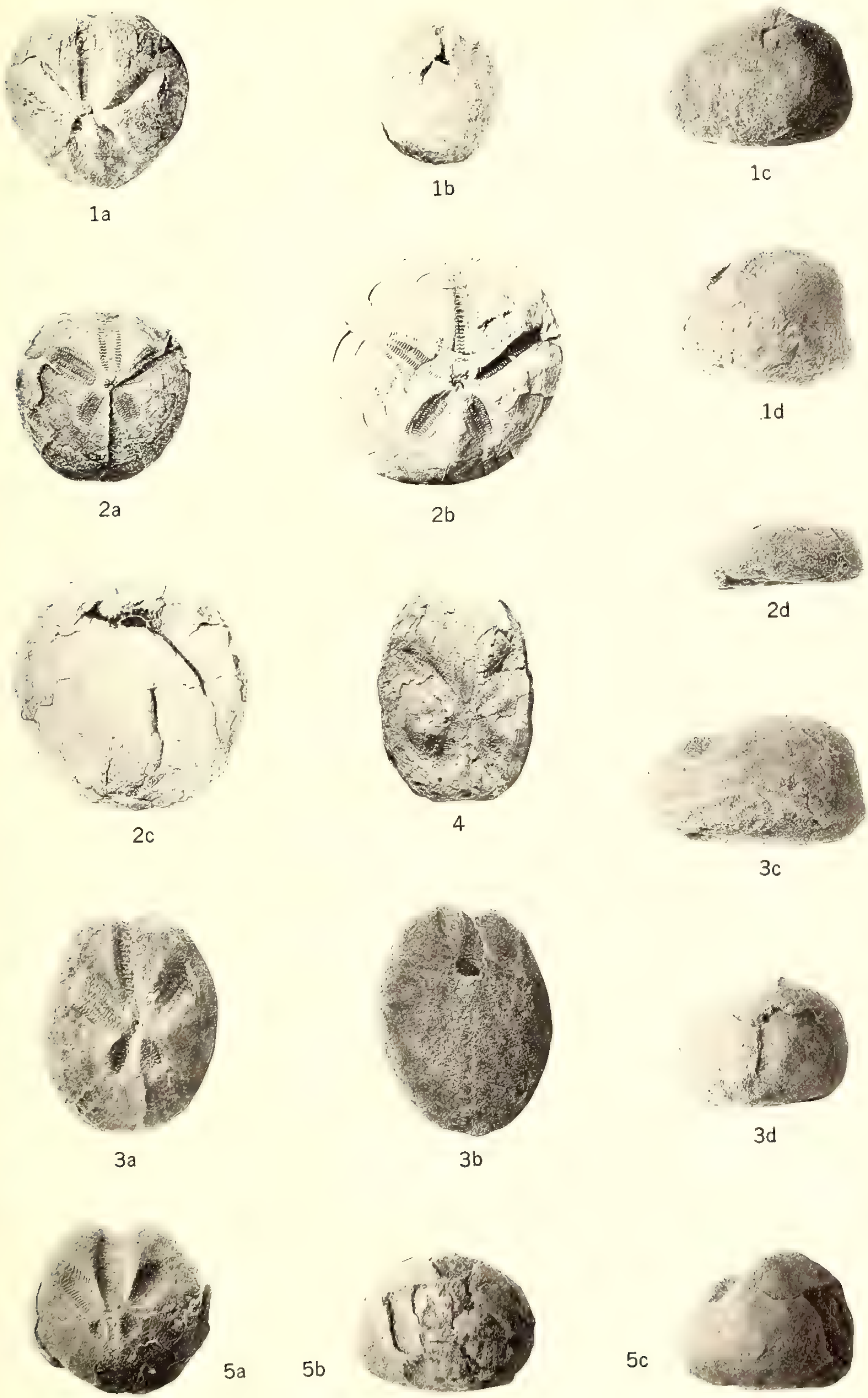
Fig. 3*d*. *Schizaster lecontei* Merriam. Same specimen. Posterior surface of test.

Fig. 4. *Schizaster californicus* (Weaver). Neotype, specimen 11259, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Approx. ½ nat. size. Bear Valley, Contra Costa County, Calif., Univ. Calif. loc. 3055. Agasoma gravidum zone, San Lorenzo series, Oligocene.

Fig. 5*a*. *Schizaster diabloensis* Kew, n. sp. Holotype, specimen 11387, Univ. Calif. Coll. Invert. Pal. Upper surface of test. South side Mount Diablo, Univ. Calif. loc. 1427. Meganos group, Middle Eocene.

Fig. 5*b*. *Schizaster diabloensis* Kew, n. sp. Same specimen. Posterior surface of test.

Fig. 5*c*. *Schizaster diabloensis* Kew, n. sp. Same specimen. Lateral surface of test.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EXPLANATION OF PLATE 42

Figures approximately natural size.

Fig. 1*a*. *Schizaster cordiformis* Kew, n. sp. Holotype, specimen 11388, Univ. Calif. Coll. Invert. Pal. Upper surface of test. South side Mount Diablo, Contra Costa County, Calif., Univ. Calif. loc. 1743. Martinez group, Lower Eocene.

Fig. 1*b*. *Schizaster cordiformis* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 1*c*. *Schizaster cordiformis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 1*d*. *Schizaster cordiformis* Kew, n. sp. Same specimen. Posterior surface of test.

Fig. 2*a*. *Schizaster martinezensis* Kew, n. sp. Holotype, specimen 11342, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Muir Station, from coral reef near Swett's Ranch, Contra Costa County, Calif., Univ. Calif. loc. 241. Martinez group, Lower Eocene.

Fig. 2*b*. *Schizaster martinezensis* Kew, n. sp. Same specimen. Lower surface of test.

Fig. 2*c*. *Schizaster martinezensis* Kew, n. sp. Same specimen. Posterior surface of test.

Fig. 2*d*. *Schizaster martinezensis* Kew, n. sp. Same specimen. Lateral surface of test.

Fig. 3*a*. *Schizaster stalderi* Weaver. Holotype, specimen 11019, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Humboldt County, Calif. Wildcat series, Upper Pliocene.

Fig. 3*b*. *Schizaster stalderi* Weaver. Same specimen. Lateral surface of test.

Fig. 3*c*. *Schizaster stalderi* Weaver. Same specimen. Posterior surface of test.

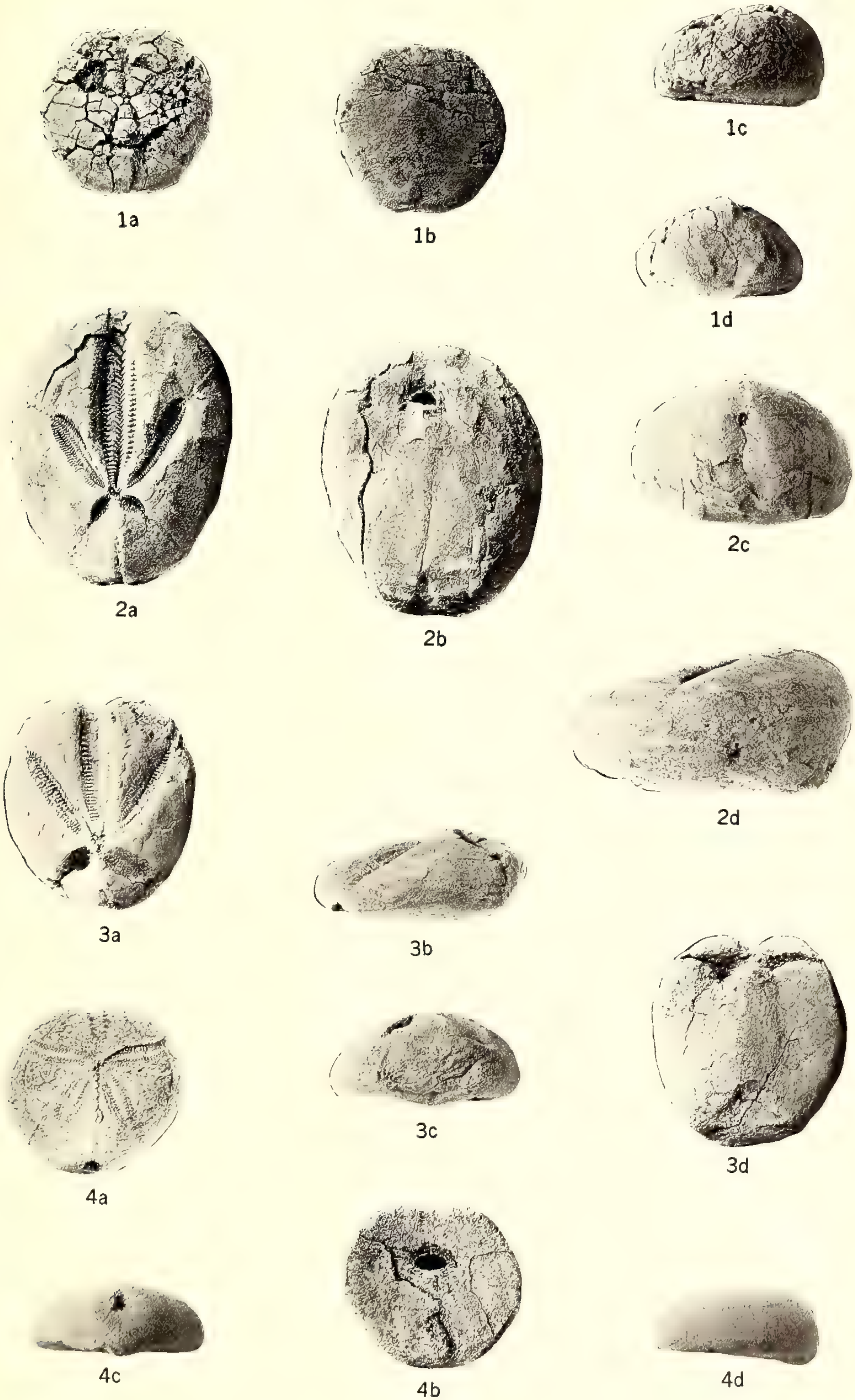
Fig. 3*d*. *Schizaster stalderi* Weaver. Same specimen. Lower surface of test.

Fig. 4*a*. *Spatangus pachecoensis* Pack. Topotype, specimen 11020, Univ. Calif. Coll. Invert. Pal. Upper surface of test. Vine Hill Station, Contra Costa County, Calif. Tejon group, Upper Eocene.

Fig. 4*b*. *Spatangus pachecoensis* Pack. Same specimen. Lower surface of test.

Fig. 4*c*. *Spatangus pachecoensis* Pack. Same specimen. Posterior surface of test.

Fig. 4*d*. *Spatangus pachecoensis* Pack. Same specimen. Lateral surface of test.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AN OUTLINE OF PROGRESS IN PALAEONTOLOGICAL RESEARCH ON THE PACIFIC COAST

BY
JOHN C. MERRIAM

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INTRODUCTION

The earliest published record known to the writer giving data on palaeontological material from the West Coast section of North America appears to be included in Beechey's report on the voyage of H.M.S. ''Blossom,'' published in 1831. In this publication Professor Buckland gives a description of the geology in the region adjacent to San Francisco Bay, and notes that, in 1827, ''Petrified bones of a cylindrical form'' were found in a cliff of sand or loose sandstone near Santa Cruz. These remains probably pertained to some member of the cetacean order which is largely represented on the West Coast, and is still, at this late date, among the groups of which the Pacific Coast history is practically unknown.

Development of the study of history of life on the western border of North America virtually began with investigation of collections

* Annual address of the President, read before the Palaeontological Society, Pittsburgh, Pa., December 31, 1917.

obtained by the Wilkes Expedition or the United States Exploring Expedition, and by the United States Government survey parties engaged in preliminary work for the purpose of determining possible transcontinental travel routes between the Mississippi River and the Pacific Ocean. Collections of molluscan remains obtained in the period of these surveys were described by T. A. Conrad in the American Journal of Science in 1848, in the U. S. Exploring Expedition Report in 1849, and in the volumes of the Pacific Railroad Survey of 1855 to 1857. This work was followed in the early sixties by that of W. M. Gabb in connection with the second California State Geological Survey. The pioneer studies of Conrad, Gabb, and others brought together a wealth of information on the history of invertebrates on the Pacific Coast, outlined the main features of the palaeontology of this region, and laid the foundation for future detailed work. Also near this period occurred the earliest important investigations of extinct vertebrate faunas in the territory west of the Wasatch, begun in 1865 by J. Leidy, and followed by O. C. Marsh on specimens obtained from the John Day region of Oregon by Thomas Condon, who was the first to recognize the significance of the fossil mammal faunas in eastern Oregon. In nearly the same period the first studies in West Coast palaeobotany were begun by Leo Lesquereux.

For approximately a quarter of a century following the period ending with the termination of the State Geological Survey of California in 1867, relatively little advance was made in palaeontological study on the western side of the continent. This stage of stagnation extended up to the time of initiation of palaeontological investigations at Stanford University and the University of California in 1892 to 1894, and has been followed by an epoch of continuous expansion in many directions through the work of faculty and students of the two universities, and by alumni who have continued their progress in scientific or technical work.

The history of palaeontological research in the Pacific Coast region, up to the present time, seems then clearly divided into two well marked periods. The first stage includes the pioneer work of Conrad, Gabb, Marsh, Cope, Lesquereux, and others. Following an interruption of about twenty-five years extending over the seventies and eighties, the second stage begins with the inauguration of work at the two universities of California, and continues with constantly increasing emphasis up to the present year.

Although the palaeontological studies of vertebrates, invertebrates, and plants have the same fundamental significance with relation to the great problems of biological history, and though all may ultimately have similar bearing upon questions of time classification and correlation, it is true that the history of these three groups has been worked out on the West Coast with rather distinct original aims and in different regions. These fields may therefore be considered separately.

HISTORY OF INVERTEBRATE PALAEONTOLOGY

To T. A. Conrad, of the Philadelphia Academy of Sciences, belongs, unquestionably, the credit of pioneering invertebrate palaeontological work on the West Coast. His descriptions of the faunas obtained from Tertiary beds near the mouth of the Columbia River give us the first discussion of a marine fauna on this side of the continent, and offer the first correlation of a West Coast fauna with that of a region outside the Pacific area. Conrad correlated the fossils from Astoria with Miocene types of the Atlantic Coast of the United States, and also with faunas of the Miocene of Great Britain. Although various modifications of this correlation have been made in later years, through use of larger and better collections, and in adjustment to a more thoroughly worked out modern classification, the studies of Conrad still hold as a good pattern for pioneer investigations, prosecuted as they were under conditions vastly different from those controlling the work of students of the present day.

Conrad's papers on the Tertiary of California, published in the Pacific Railroad surveys, beginning with the discussion of the Eocene of Canada de las Uvas and the Miocene of Ocoya Creek, in volume 5 of these reports, give us again an excellent form of preliminary work, in which the determinations of age and descriptions of species are as satisfactorily done as one could expect under the conditions. His studies were continued in volumes 6 and 7, through description of faunas ranging rather widely over the Tertiary.

With the inauguration of the second Geological Survey of California in 1861, under the direction of J. D. Whitney, palaeontological study of the West Coast faunas was given an unusually important place. It is evident that Whitney realized the necessity for careful studies of this nature, in order to make possible necessary correlation

over the California region, and to permit comparison between the Pacific Coast province and other areas of the world. The absence of adequate maps prevented extensive use of stratigraphic criteria, and it was clear that progress in geological study of the sedimentary formations of California would be impossible without full data concerning the palaeontological sequence of typical sections. Whitney's view of this question seems to be expressed by his inclusion of two volumes of palaeontology in the three representing his Report of the Geological Survey of California. In a later volume, on the Auriferous Gravels of California, published by Whitney, considerable emphasis is again placed upon the palaeontological aspect of the work.

The first volume of the Palaeontology of California, published in 1864, included a study of the Carboniferous and the Jurassic, by F. B. Meek, and a description of Triassic, Cretaceous, and Eocene faunas, by W. M. Gabb. Considering that this work was of the pioneer type and executed within the three years following the beginning of the survey, we must grant that it was a most excellent contribution to the faunal study of North America. Volume 2, published in 1869, is another very important contribution, representing entirely the work of Gabb, and including a wide range of faunas from the Cretaceous to the later Cenozoic. Barring the unfortunate confusion of the Cretaceous and the earlier Eocene, the work of Gabb must be considered as a model, upon which improvement in method and form have scarcely been made in later publications originating in this region.

The conclusion of the State Geological Survey work, under the hand of Gabb, furnished for the California region an excellent palaeontological series, beginning with a somewhat scanty fauna of the Carboniferous and ranging through to the Pleistocene. To many it appeared that the invertebrate series of California had already been rounded out, and that later studies, though shifting lines here and there, would not greatly alter the fundamental conclusions reached by Gabb and Whitney. This publication, taken with the earlier studies of Conrad, did undoubtedly furnish the major outlines of palaeontological sequence for invertebrate faunas. Later studies have shown that lines may be moved slightly up or down; that generic and specific descriptions may be modified; that biological and geological classifications must be altered through further subdivision; and that significant additions must be made. I believe, however, that too great praise cannot be given to the students of this pioneer period for the large measure of result coming from comparatively few years of work, under conditions

much less favorable than those now obtaining, and with knowledge of general palaeontological problems very much less advanced than at the present moment.

Between the period marking the conclusion of work of the second Geological Survey of California and the initiation of palaeontological work at the California universities, a number of significant palaeontological studies relating to the invertebrate faunas of the West Coast, were published. Belonging to this intermediate stage is the important work of C. A. White, who devoted special attention to the Cretaceous problem of California and made valuable additions to knowledge in bulletins of the United States Geological Survey. Important reviews of the California faunas in this period are the United States Geological Survey bulletins on the Eocene, by W. B. Clark, and on the Miocene, by W. H. Dall. Also having its inception in this period, is the beginning work of T. W. Stanton, of the United States Geological Survey, resulting in the publication of important papers falling within the limits of the next period. Among the papers by Dr. Stanton, special mention is to be made of his study of the fauna of the Knoxville Cretaceous, published in 1895, and of an important paper on the fauna of the Shasta and Chico formations, published in the bulletins of the Geological Society of America in 1893.

In the latter part of the intermediate stage comes also the very significant study of Alpheus Hyatt on the Jurassic and Triassic of California, presented in two papers in bulletins of the Geological Society of America in 1892 and 1894. In these contributions a number of new forms were described and valuable evidence concerning the relationship of these faunas was presented.

Toward the end of this intermediate period, determinations of faunas of Cretaceous and Tertiary age were made for bulletins of the California State Mining Bureau by J. G. Cooper, formerly associated with the State Geological Survey. Dr. Cooper also described and figured a number of new species, including both marine and fresh-water types.

The second period of active investigation of invertebrate palaeontology on this coast began with the work of James Perrin Smith on faunas of the older sedimentaries, including the Jurassic, Triassic, and Carboniferous in regions bordering the Sierra. Papers by Professor Smith, in the bulletins of the United States Geological Survey and the Journal of Geology, made important contributions to assembled information on the age of the auriferous slates of the Sierra

Nevada, and added to our knowledge of the Jurassic and Triassic faunas. Following the discovery of a most extraordinary section of early Mesozoic rocks in Shasta County, California, by H. W. Fairbanks, and the recognition of the unusually well-preserved Triassic remains in this section, Professor Smith began an epoch-making series of studies on the West American Triassic. This investigation, initiated in studies of the upper division of the Triassic of northern California, was extended to the middle and lower Triassic of Nevada and Idaho. The results of these researches have given us a monumental work covering the most significant series of Triassic deposits of the Western Hemisphere, and have also given us one of the most important contributions to our knowledge of the Triassic faunas and of the early Mesozoic Cephalopoda in the whole field of palaeontological literature.

Following the studies of Professor Smith on the earlier rocks of the California section came the work of G. H. Ashley of Stanford University on the Tertiary faunas, and that of Ralph Arnold of Stanford University on the Pleistocene of the San Pedro region. Arnold's study of the Pleistocene, beginning with the first assembling of material by Delos Arnold, made a very significant addition to our knowledge of the latest faunas of the Cenozoic, and furnished the basis for study of the whole marine Pleistocene of the Pacific Coast region. Arnold's study of the Pleistocene fauna was followed at Stanford University and later on in the Geological Survey by investigations covering especially the middle and later Tertiary of southern California. Arnold's paper on the Tertiary and Quaternary Pectens of California represents the most important study of a group of Tertiary invertebrates on the West Coast published up to the present time. Numerous papers by Arnold, appearing mainly in the bulletins of the United States Geological Survey, and representing the results of excellent work on the oil producing formations of California, include studies of the Oligocene, lower, middle, and upper Miocene, the Pliocene, and the Pleistocene. These publications register a distinct advance in study of Tertiary faunal sequence and in our knowledge of the composition of the Tertiary faunas of the Pacific Coast. Certain papers by Arnold were in part published with the coöperation of George H. Eldridge, geologist of the Geological Survey, and later with Robert Anderson, of the Geological Survey.

Beginning with the second period and continuing up to the present time, important investigations were carried on by F. M. Anderson

at Stanford University, University of California, as geologist with the Southern Pacific Company, through the California Academy of Sciences, and later as an independent investigator. Anderson's papers on the Cretaceous deposits of the Pacific Coast, published through the California Academy of Sciences in 1902, marked an advance in the development of our knowledge of this fauna on the West Coast. His papers on the faunas of the middle and later Tertiary, and covering important phases of this life on both eastern and western sides of the San Joaquin Valley, contributed much to our knowledge of Cenozoic invertebrate palaeontology. Later studies in coöperation with Bruce Martin added very significant data relative to this field.

A revision of the Eocene faunas of the California region was begun by R. E. Dickerson in 1909 and was continued without interruption up to 1917. This work began with the discovery of definite evidence of separation of the lower Eocene or Martinez fauna from the Chico Cretaceous and the later Eocene fauna represented in the Marysville Buttes. A monograph on the Martinez fauna added much to knowledge of this stage of the Eocene. Numerous shorter papers have been issued on various aspects of the Eocene of the whole Pacific Coast region, the work on later Eocene culminating in a review of the Tejon fauna. In the geologic sense one of the most important contributions of this work lies in the presentation of evidence of the Eocene age of the marine Ione beds. Dickerson's studies of the Eocene greatly increase this fauna, and give a better view of the geographical distribution of its various phases.

In 1913, E. L. Packard undertook a further study of the Cretaceous of the Pacific Coast, commencing with investigation of an interesting section in the Santa Ana Mountains of southern California. The work has added considerably to our knowledge of faunal range and geographical distribution of the late Cretaceous marine invertebrates of this coast.

Dr. Packard has also carried on an intensive investigation of the mactrine pelecypods of the West Coast begun under the direction of Professor C. E. Weaver at the University of Washington. This study has been one of the most difficult and most carefully conducted investigations of a group of fossil invertebrates accomplished on the Pacific Coast.

The Miocene, especially in its later phases in California, has been the subject of long-continued and intensive study by Bruce L. Clark,

whose paper on the San Pablo fauna represents the most minute analysis of a Cenozoic fauna of the West Coast appearing since the publication of Arnold's monograph on the San Pedro Pleistocene. As yet no other palaeontological study in California has given us such detailed dissection of a stratigraphic sequence with such careful discussion of the significance of sequence. This work is being continued in the upper portion of the Miocene below the San Pablo. Dr. Clark has moreover made an exhaustive study of the Oligocene of middle California, and an extensive publication on this fauna is now in press. He has also carried out a study of the whole Oligocene fauna of the West Coast to be presented in monographic form in the near future.

The Pliocene faunal problem of California has been attacked by Bruce Martin, of the University of California, who explored widely over the West Coast, and has made two significant contributions through the University of California Publications: one, a description of new species, the other, a general faunal study of the Pliocene of middle and northern California, appearing in 1916. The work of W. A. English on the Fernando Pliocene near Newhall, and especially the recent studies of J. O. Nomland on the Jacalitos and Etchegoin of the Coast Range region have advanced our knowledge of the southern Pliocene considerably beyond the stage to which it was carried by the excellent work of Arnold and Anderson and F. M. Anderson. Nomland's analysis of the Etchegoin Pliocene fauna and of the wonderful 10,000 foot section in which it is found, contributed much to understanding of the faunal composition of the Pliocene and of the faunal sequence.

The Pacific Coast Province has been assumed by the writer to be divisible into two major parts: the California Area and the Puget Area, the latter including the region of western Washington and Oregon. In the Puget region, study of invertebrate faunas is much less advanced than in the California Area, due largely to the smaller number of local investigations.

Following the early work of Conrad and others, comparatively little was done in the region of the northwest until the first decade of the present century in which we have an important reconnaissance paper by Ralph Arnold on the faunas of the Pacific Coast region of the Olympic Peninsula published in a bulletin of the Geological Society of America in 1905. In 1909 W. H. Dall published a large and very important study on the Miocene of Astoria and Coos Bay,

Oregon, in which he reviewed all previous work, contributed largely to the middle Tertiary fauna, revised the determinations, and organized all of the much scattered literature contributed up to that time. Dall's work was followed by the studies of C. E. Weaver at the University of Washington, Arnold and Hannibal, Bruce Martin, R. E. Dickerson, and others. Especially the recent papers of Weaver, published by the Geological Survey of Washington and by the University of Washington, and of Arnold and Hannibal, in the Proceedings of the American Philosophical Society, have opened up a wide and almost unknown field in invertebrate palaeontology of the northwest. Much still remains to be known of the composition, sequence, distribution, and age of the faunas of the Puget Area, and no field of invertebrate palaeontology of the West Coast may be expected to furnish larger contributions in the next decade.

With the exception of James Perrin Smith's papers on Triassic Cephalopoda, Ralph Arnold's monograph of the Tertiary and Quaternary Pectens of California, and Packard's investigation of the mactrine pelecypods, the greatest part of the work on West Coast invertebrate palaeontology has up to this time concerned itself largely with discussion of faunal sequence. In addition to the description of special groups already discussed, particular reference should be made to the work of W. S. W. Kew on the Echinoids, resulting, after several years' work, in a monographic study of the whole group as represented on this coast. Another group to which small additions have very recently been made is that including the corals, which have been worked through by J. O. Nomland.

HISTORY OF VERTEBRATE PALAEONTOLOGY

With the exception of a number of scattered notes on the occurrence of vertebrate remains in various parts of the Pacific Coast region, the earliest publication on this phase of palaeontological work is that of Louis Agassiz, describing a fossil fish fauna obtained by the Pacific Railroad Survey in Tertiary beds of the Kern region in the southeastern part of the Great Valley of California. This paper, containing the description of eleven species of the shark-skate group, was published in 1856 and remained the largest contribution to our knowledge of the fishes of the region west of the Wasatch until the appearance of David Starr Jordan's discussion of the fossil fishes of California, in 1907, over half a century later.

Excepting the fishes described by Agassiz, very few vertebrate remains were discovered outside the region of eastern Oregon during the period of pioneer work under the government and state surveys. A few references were made to occurrence of fishes and cetaceans, and a small series of fragmentary specimens of land mammals collected by the Geological Survey of California from middle Tertiary to Pleistocene strata in the Sierra region of California was described by Joseph Leidy. Also a few fragmentary vertebrate remains were obtained near the region of Tulare Lake on the western border of the San Joaquin Valley, from beds near Livermore, and at other scattered localities. These collections included fragmentary material representing rhinoceros, two or more extinct horses, tapir, elothere, camel, bison, elephant, mastodon, great wolf, and lion. The most important of these descriptions of collections obtained in California is the assembling of data from all sources by Leidy in J. D. Whitney's great work on the gold-bearing gravels of the Sierra Nevada, published in 1879.

In 1868, Leidy published the first description of a West Coast or Great Basin Mesozoic reptile. His material consisted of several very fragmentary specimens from the middle Triassic of Nevada. No other paper in the field of reptilian palaeontology of the region appeared until 1895.

By far the most important contributions to our knowledge of the history of vertebrates in this West Coast region in the pioneer period are those originating in 1861 with the studies of Thomas Condon on the mammal faunas of the John Day region of Oregon. A small collection of the fossil specimens collected by Condon was obtained by Leidy and described in 1870. Following a period of ten years of exploration by Condon, Professor O. C. Marsh of Yale visited the John Day region in 1871, and began a series of explorations, resulting in the publication, between 1873 and 1894, of a series of seven or eight papers relating to the remarkable Tertiary faunas discovered.

In 1878, E. D. Cope began systematic collecting in the John Day region, with parties under the direction of J. L. Wortman and C. H. Sternberg. In over thirty publications issued between 1878 and 1889, Cope presented results of his important studies covering nearly the whole range of the Oligocene, Miocene, and Pliocene faunas of eastern Oregon and marking an important epoch in the development of American palaeontology.

It was toward the end of the pioneer period of palaeontological investigation that Major Hancock of Los Angeles called to the attention of William Denton of Boston the vertebrate remains in asphalt beds on the Hancock Ranch, now known as the place of occurrence of the Rancho La Brea Pleistocene fauna. Denton gave a good description of the locality, but his reference to the fauna in the Proceedings of the Boston Society of Natural History of 1875 seems to have escaped notice of all investigators until after the independent discovery of the significance of these deposits in 1905.

In the literature of California, Nevada, western Oregon, and Washington, there are sporadic references to occurrence of fossil vertebrates discovered in this field between the first and second periods: such are the mention of a very few mammal remains in the Great Basin Province discussed in King's Report of the Fortieth Parallel Survey in 1878, and the reference to occurrence of cetacean and sirenian remains in the marine deposits of California by Leidy, Cope, and Marsh.

Following the beginning of palaeontological work at the two universities of California, a study of the marine Triassic reptiles was begun by J. C. Merriam in 1895, culminating in the publication of a monograph on the new order Thalattosauria in 1905 and one on the Triassic Ichthyosauria in 1908, the latter setting forth such evidence on the evolution of the ichthyosaurs as was then available. Work on the John Day faunas by parties from the University of California in 1899 and 1900 led to a series of papers including studies of the faunal sequence, discussion of the principal groups, and a summary of the fauna by J. C. Merriam and W. J. Sinclair between 1902 and 1907.

Mammalian faunas of three important Pleistocene caverns of California, represented in Potter Creek, Samwel, and Hawver caves, were secured and described by Sinclair, E. L. Furlong, and Merriam between 1902 and 1909. These studies gave for the first time a knowledge of the Pleistocene mammals in the higher, partly forested areas of the California region, and opened one of the most fascinating phases of study in the field of mammalian history.

In 1901 an expedition from the University of California visited the Fossil Lake Pleistocene of eastern Oregon and secured a valuable collection, of which the bird remains have been described by L. H. Miller.

Previously unknown Tertiary deposits representing the middle Miocene and the Pliocene in northwestern Nevada were explored

by parties from the University of California in 1906 and 1909. The faunas of these deposits were described by J. W. Gidley, E. L. Furlong, Miss Louise Kellogg, and J. C. Merriam, between 1907 and 1910. The most significant contributions in this work were the additions made to our knowledge of the earlier Pliocene, heretofore unknown in the western area with the exception of a meager fauna from the Rattlesnake beds of the John Day region. Indication was also given of the broader relations of this fauna to those of the Great Plains region of America and of Old World areas such as China, India, Persia, Greece, and France.

Between 1911 and 1915, University of California parties worked over previously unexplored mammal-bearing formations of the Mohave Desert area and brought to light faunas representing at least four stages of the Cenozoic sequence. Of these the Phillip's Ranch middle or lower Miocene, the Barstow upper Miocene, and the Ricardo lower Pliocene were represented by mammal assemblages previously unknown in the region west of the Wasatch. The Manix fauna of the Mohave area is the best known group of Pleistocene forms obtained from any one locality in the Great Basin region. The Manix Pleistocene and the Phillip's Ranch Miocene have been described by J. P. Buwalda, the discoverer of these two very interesting faunas.

An important mammal fauna of the Great Basin Miocene was obtained near Cedar Mountain in 1912 by C. L. Baker and J. P. Buwalda.

In 1905 a small amount of material secured by W. W. Orcutt of Los Angeles furnished the motive for beginning extensive work on the Rancho La Brea Pleistocene fauna, and for the initiation of a series of publications continuing through numerous issues of bulletins in the University of California Publications up to the present time.

The great quantity of bird remains secured at Rancho La Brea was made the basis of L. H. Miller's first study of the fossil birds of the Pacific Coast region, this work being later extended to include all avian remains from the West Coast. Many papers have been contributed by Dr. Miller and the results of his studies in this field constitute one of the unique and important contributions to American palaeontology.

Preliminary papers on the carnivores and ungulates of Rancho La Brea have been published by J. C. Merriam. Studies on the Pleistocene rodents have been contributed by Miss Louise Kellogg and Lee R. Dice. An exhaustive study of the edentates of Rancho La

Brea now in progress by Chester Stock has been extended to include the whole problem of edentates on the West Coast. Other contributions to the study of the ungulates from the asphalt beds have been made by W. P. Taylor and A. C. Chandler, while the batrachians have been reported upon by C. L. Camp.

Not the least significant of the studies in vertebrate palaeontology on the West Coast are those concerning the faunas of mammal-bearing deposits having a well understood stratigraphic relation to the marine Tertiary series west of the Sierra Range. Especially important are the collections obtained by parties working in the Coalinga region under the leadership of Bruce L. Clark in 1913. Mammal material secured at that time represents at least three important horizons of the Miocene and Pliocene. These collections may with some degree of satisfaction be compared with the Tertiary mammal series of the Great Basin region, and furnish the most valuable evidence bearing on correlation between the Great Basin and Pacific Coast formations thus far obtained.

Growing out of the work in vertebrate palaeontology west of the Wasatch, has come an effort to construct a correlation scheme of the mammal-bearing Tertiary formations of the Great Basin Province for use in fuller understanding of the palaeontological sequence. The correlation plan includes consideration of evidence of any and every kind that may be used to furnish us with information concerning the time relations of formations and their contained faunas. This work, under way for many years, can obviously never be completed. It is being presented for publication in the form in which it stands in 1917. As an outcome of the correlation it has become clear that further progress in our mammal history can be advanced most quickly by careful mapping and detailed study of the faunal zones in an area containing a considerable portion of the Cenozoic section. Such an area is found in the John Day region of Oregon. Through coöperation with the United States Geological Survey and the University of Oregon work on a detailed monographic study of this region was begun in 1916. Intensive study of a small portion of the most imperfectly understood part of the section, represented by the Rattlesnake Pliocene and Mascall Miocene, has given unexpectedly large returns. Continuation of this work promises the beginning of a new epoch in interpretation of West American vertebrate faunas, and will greatly increase the scope of our studies so far as we have relation to world problems of evolution and distribution.

The most recent and one of the most interesting contributions to Pacific Coast palaeontology is that of Childs Frick, who, with unexcelled patience and persistence, has secured from the apparently barren hills of San Timoteo near San Bernardino, California, a series of Pliocene to Pleistocene mammal assemblages. These faunas include, with Asiatic types like the great bear, *Hyaenarctos,* one of the most interesting series of specimens suggesting the origin of the modern horse, *Equus,* that has yet appeared in America.

Studies of the fossil marine mammals known in West Coast deposits were planned beginning in 1895, but have only recently been realized in part through a review of all known pinniped remains from these deposits by Remington Kellogg.

Other studies of vertebrate faunas now under way, and to which reference might be made, include the discussion of a considerable number of special groups as the antelope-like ungulates, and the cats. Among the marine forms the cetaceans are being investigated. As yet comparatively little is known of this last group although excellent collections are already assembled for study.

Vertebrate palaeontology in the West Coast region has not yet reached the stage of development of invertebrate palaeontology in completeness of material available. In other particulars, as in the study of biological groups and evolutionary series, it is in many respects in advance of invertebrate study, excepting that aspect of it so remarkably exhibited in James Perrin Smith's work on the Cephalopoda.

HISTORY OF PALAEOBOTANICAL INVESTIGATIONS

Our knowledge of the history of plants in the Pacific Coast region is much more imperfect than that of invertebrates or of vertebrates. During the pioneer period, the attention given to plants was not comparable to that bestowed upon either group of animals. During the second period the absence of local palaeobotanists has greatly retarded progress in this particular field. Up to the present time, a large part of the work done on the Pacific Coast has been carried on with the assistance or through the coöperation of the United States Geological Survey.

The earliest publication on palaeobotany of the West Coast known to the writer is one published by Leo Lesquereux in 1859 in the American Journal of Science and covering descriptions of "Some

Fossil Plants of Recent Formations,'' including species from Vancouver Island and Bellingham Bay, Washington. In 1883, J. S. Newberry of Columbia University published descriptions of sixteen new species of plants from the flora of the John Day region, this material having been obtained by Thomas Condon. In 1878, Lesquereux published a monograph of the Auriferous gravel flora in connection with J. D. Whitney's great report on the gravels. In 1883, Lesquereux in his monograph on Cretaceous and Tertiary floras described large collections from the Eocene and Miocene of the John Day region obtained by C. D. Voy, a professional collector from California. In 1889, Lesquereux published again a large series of species from the same horizon in the Proceedings of the United States National Museum.

One of the most important contributions concerning the Mesozoic flora of the Pacific Coast is a paper by William Fontaine on the Jurassic Flora of Douglas County, Oregon, published in 1905 in a monograph on the Mesozoic flora of the United States by Lester F. Ward, Fontaine and others. In the same work is an important article by Fontaine on the flora of the Shasta group of California.

Significant work on the fossil plants of the Pacific Coast region is that carried on by F. H. Knowlton of the United States Geological Survey within the second period of palaeontological study on the West Coast. The work of Knowlton includes an intensive study of large collections representing the Puget flora from the Eocene of Washington, as yet unpublished; a complete revision of the Tertiary flora of the John Day region in eastern Oregon published in a bulletin of the Geological Survey in 1902; and a revision of the flora of the auriferous gravels of California and allied floras appearing in Lindgren's paper on the Tertiary gravels of the Sierra Nevada of California published as a Professional Paper of the United States Geological Survey.

Dr. Knowlton's studies of the fossil plants of eastern Oregon have shown clearly the presence of at least four floras: two in the Clarno Eocene, one in the John Day Oligocene, and one in the Mascall Miocene.

Dr. Knowlton has also discussed in detail the problem of the Jurassic age of the supposed Jurassic flora of Thompson Creek, Oregon, and in numerous other short articles, either independent or accompanying reports of the Geological Survey, he has added much to our knowledge of the Tertiary floras of the whole western region.

In spite of the good work of Dr. Knowlton and others, the problems of West Coast palaeobotany are at the present day in a stage much further from final clarity than those in other phases of palaeontological investigation. A nearly continuous procession of expeditions from universities and from various government organizations has spent years of work in collecting vertebrates and invertebrates for the purpose of increasing our series to such a point that we may better understand the biological and time classification of the groups concerned, but our study of the history of plants has been based almost entirely upon more or less incidental collecting in field operations carried on for purposes other than palaeobotanical research, and covers an exceedingly short period compared with that given to study of other groups.

CONCLUSIONS

The relative isolation of the field for palaeontological study on the western side of the continent has tended to distinguish to some extent the problems of this area from those of the lands to the east. Separated as the Pacific Coast is from other regions by high mountains and wide oceans, it is natural that its isolated investigators should tend to separate their special researches rather widely from those of other workers. It is also clear that in past periods the life of this province has in its evolution tended to take on provincial characters differentiating it to some extent from that of other parts of the world. It is, however, true that the study of every group leads finally to a point at which we find ourselves forced to relate our local problems to the great world questions of life history.

In certain aspects the history of life on the Pacific Coast is imperfectly recorded. In other phases the information is available, but is as yet only partially examined. For a considerable portion of the earlier story of life we have only a meager record compared with that of the Atlantic Coast. Our history of plants is largely that of the later periods. Of the age of amphibians we have no amphibian record. Of the wonderful world history of the great reptile group, we know but a limited portion of the story of two divisions. In the history of mammals we lack entirely the long record of Eocene time. After subtraction of the factors which are poorly represented there is, however, enough remaining to give us a most extraordinary history compared with that of most portions of the earth's crust. Progress in our

difficult work of interpreting this record has already been made, but the labor required to obtain adequate understanding of the history of this region must stretch far into the coming centuries before the end will be in sight.

The next four or five decades will see great advances in interpretation of detail in sequences of local faunas. We shall finally build up a system in which our West Coast correlations will become consistent with themselves. At the same time there will be a reaching out to obtain an interpretation of local evolution through knowledge of the great waves of world migration of organisms, and through better understanding of the complicated physical history of this planet. In time our story will be fitted into that of America in the large and ultimately it will become an interpretable part of the complicated record of life progress for the earth as a whole. Only the beginnings have been made—the real problems are yet to be solved—the broader contacts are still to be made.

As I conclude the thought uppermost in my mind concerns especially the part which our western work should have ultimately in assisting to interpret the world scheme of evolution, but in framing a vision of the larger use of the materials in process of accumulation we must remember that this object is to be attained only through coöperation and assistance of our colleagues across the continent to the east and over the ocean to the west.

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The following titles are not intended to furnish a complete list of contributions to the palaeontological literature of the Pacific Coast and Great Basin provinces. The list is divided into three sections, namely, (1) Invertebrate Palaeontology, (2) Vertebrate Palaeontology, and (3) Palaeobotany.

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BY
CHESTER STOCK

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CONTENTS

Introduction

During the field season of 1918, Professor B. L. Clark, with a party of advanced students in palaeontology from the University of California, made a reconnaissance of the Tertiary formations on the southwestern border of the San Joaquin Valley some thirty to forty miles south of Bakersfield. In the course of this study fragmentary mammalian remains were discovered in certain land-laid deposits typically exposed in the vicinity of Tecuja Cañon. Later Mr. E. L. Furlong and the writer, at the request of Professor John C. Merriam, made a careful and detailed examination of the region where the vertebrate materials had been found and extended the search to Pleito Cañon, several miles to the northwest.

The fauna secured from these deposits is unfortunately not large. It is to be regretted also that the forms which have been found are preserved in such fragmentary state, for definite specific determination

can not be reached in any of the types nor is generic recognition possible in two of them. Nevertheless, the collection is of decided interest, not only because it indicates perhaps the earliest Tertiary mammalian assemblage of definite stratigraphic position as yet known from California, but also because it will aid materially in establishing a more nearly complete correlation between West Coast marine deposits and Tertiary beds of the Great Basin and of the Great Plains.

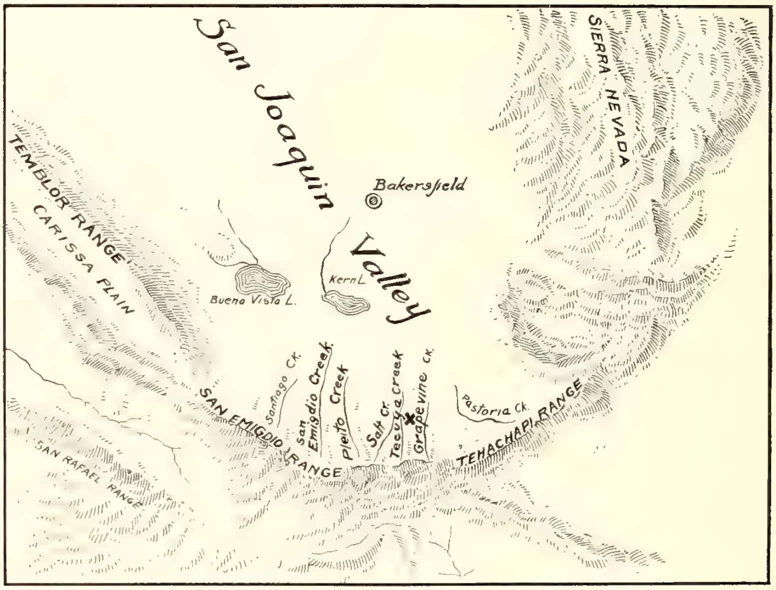


Fig. 1. Map of southern end of San Joaquin Valley, California, showing general location (×) of mammal-bearing beds in Tecuja Cañon. The base line of the map is approximately east-west.

Occurrence and Nature of Fossil Remains

B. L. Clark and others who have examined the sequence of Tertiary sediments in the vicinity of Tecuja Cañon, consider the Monterey Series as here exposed to consist in its basal part of land-laid beds in which red colored sandstones and shales are the most striking lithologic members. Lavas and tuffs are also present. These deposits apparently pass upward into marine sediments without evidence of unconformity. It has been noted, however, that the marine phase of the Monterey above the red beds was introduced, at least in this region, by the formation of conglomerates which occur at several horizons. The vertebrate remains were all obtained from the red colored strata at the base of the section.

On the east or southeast side of Tecuja Cañon, where mammalian remains were first found, the Monterey has suffered greater deformation than in the region farther to the west.

Mammalian fossils occur nowhere abundantly in the so-called red beds. The lack of large collections of vertebrates may be ascribed in part to the position of the strata and in part to the fragile nature of the osseous material. It is possible also that peculiar environmental conditions may have been factors unfavorable to burial and preservation of remains, a possibility which would also account for the paucity of types. The collection consists of relatively numerous individuals of the genus *Hypertragulus*—a form related to the early camels or deer, a rhinoceros, and a squirrel-like rodent. At several localities a snail of the *Helix* type occurs. The fossil remains were collected between Salt Creek and Tecuja Cañon and to the southeast of the latter cañon, but from red colored deposits occurring to the west of Salt Creek no material was obtained. The productive zone may be designated the Tecuja beds.

Description of Material

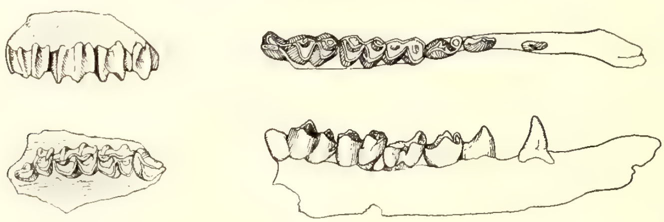
HYPERTRAGULUS, sp.

Material representing this genus consists principally of fragmentary jaws and parts of the dentition. A few skeletal structures were also obtained, but no specimen was sufficiently well preserved to give the essential structures of the skull. Comparison has been made particularly with materials referred to *Hypertragulus* from the John Day Oligocene deposits of eastern Oregon. Judging from the remains available, the California species seems to be somewhat smaller than the John Day form.

In the Tecuja Cañon specimens the upper molars are preserved often in series, and in several $P^{\underline{4}}$ remains intact. $P^{\underline{4}}$ has much the shape and development of the corresponding tooth in John Day specimens. In the molar teeth the mesostyle is absent, while the median internal style is present between anterior and posterior crescents. A narrow cingulum is often developed along the anterior face of the molars. The degree of hypsodonty exhibited by the upper molars of the Tecuja form does not appear to differ from that possessed by molars from the John Day beds showing comparable stages of wear.

In the most nearly complete lower jaw, no. 23600, figure 3, from the red beds of the Tecuja Cañon region, $P_{\overline{2}}$ is separated from $P_{\overline{3}}$ by a

diastema the length of which equals that in the John Day specimen, no. 1343, Univ. Calif. Col., described by Sinclair.[1] The degree of complication of enamel pattern in $P_{\overline{4}}$ is as great as in the corresponding tooth of the John Day species. The length of the inferior tooth series, $P_{\overline{3}}$ to $M_{\overline{3}}$, inclusive, is, however, distinctly shorter than in no. 1343 from the John Day beds. The California specimens show closer resemblance to the John Day species than to *Hypertragulus ordinatus* in which, according to W. D. Matthew, $P_{\overline{2}}$ to $M_{\overline{3}}$ constitute a series without diastema. *H. ordinatus* occurs in the Lower Rosebud (Lower Miocene) of South Dakota.



2 3

Figs. 2 and 3. *Hypertragulus*, sp. Superior and inferior dentition, natural size. Fig. 2, P^4 to M^2 inclusive, no. 23598, occlusal and lateral views; fig. 3, $P_{\overline{2}}$ to $M_{\overline{3}}$ inclusive, no. 23600, lateral and occlusal views. Red beds, Tecuja Cañon, California.

The genus *Hypertragulus* is well represented in faunas of the John Day deposits, where it occurs in the middle or Diceratherium beds, and in the upper or Promerycochoerus beds. Dr. Matthew, who has kindly furnished information regarding *Hypertragulus* and its geologic range in the Great Plains region, states[2] that the genus is found in the Oligocene, its vertical distribution extending upward from the Lower Titanotherium beds to the Miocene. He notes further the occurrence of a species in the lower Rosebud (Lower Miocene) of South Dakota; the apparent absence of the genus in the Lower Harrison (upper division of the Lower Miocene); and the certain absence of *Hypertragulus* in formations later in age than the Lower Harrison.

Measurements of No. 23600

Length of dental series, $P_{\overline{3}}$ to $M_{\overline{3}}$ inclusive	29.8 mm.
Length of diastema behind $P_{\overline{2}}$	3.6
Depth of ramus below middle of $P_{\overline{3}}$	8

[1] Sinclair, W. J., New and imperfectly known rodents and ungulates from the John Day series, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pp. 128–129, 1905.

[2] Letter addressed to writer, dated November 11, 1918.

CAENOPUS? or DICERATHERIUM?, sp. indet.

Three fragmentary superior teeth pertaining to a single rhinoceros, no. 23614, figures 4 and 5, are available for study. These specimens represent $P^{\underline{1}}$ and apparently $P^{\underline{3}}$ and $P^{\underline{4}}$. They correspond fairly closely in size with similar teeth of Oligocene rhinoceroses and particularly with those of *Caenopus occidentalis* as figured by Osborn.[3] In the character of size they are comparable also to some specimens belonging to rhinoceroses from the John Day. The teeth from the red beds of Tecuja Cañon do not seem to have acquired a noticeably greater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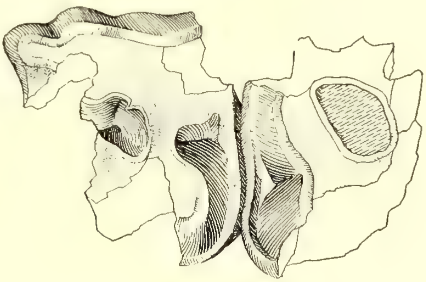
5

Figs. 4 and 5. *Caenopus?* or *Diceratherium?*, sp. indet. Superior cheek teeth, no. 23614, occlusal view, natural size. Fig. 4, $P^{\underline{1}}$; fig. 5, $P^{\underline{3}}$? and $P^{\underline{4}}$. Red beds, Tecuja Cañon, California.

degree of hypsodonty than that possessed by teeth of Oligocene rhinoceroses of the John Day.

In $P^{\underline{1}}$ (fig. 4) the parastyle is broken away, but the rest of the crown remains intact. It exhibits a postprotoconal valley and a postfossette as in the corresponding tooth of Oligocene aceratheres. The transverse diameter across the posterior side is somewhat greater than in *C. occidentalis*. As remarked by Osborn, $P^{\underline{1}}$ in the Oligocene forms is subject to considerable variation.

The two remaining teeth (fig. 5) of the rhinoceros from Tecuja Cañon are badly injured. From the parts which remain a size is indicated which would place them rather with the premolars than with the molars of the superior dentition. They are considered as premolars in the present discussion, having been determined tentatively as $P^{\underline{3}}$ and $P^{\underline{4}}$. The cingulum is well developed in these teeth along the preserved portions of the anterior and posterior borders. An interest-

[3] Osborn, H. F., The extinct rhinoceroses, Amer. Mus. Mem., vol. 1, pt. 3, pl. 13, fig. 5, 1898.

ing feature of each of the specimens is the preservation of the prefossette, thus presenting a very close similarity to *C. occidentalis* as figured by Osborn. They are more like the corresponding teeth of the latter species in their enamel pattern than they are like those of the species of rhinoceroses from the Agate Spring quarry of Nebraska.

Regarding the evolution of premolar teeth in aceratheres, Professor Osborn[4] has remarked: "The stages in the assumption of the molar pattern by the premolars furnish the key to the Oligocene species of Aceratheres, and are thus of great importance." In the changes of crown shown by $P^{\underline{3}}$ and $P^{\underline{4}}$ the principal modification which takes place, according to Osborn, is the opening inward of the prefossette to form the valley between protoloph and metaloph. The teeth of the rhinoceros from Tecuja Cañon, when viewed in the light of the interpretation of premolar evolution in Oligocene members of the group, exhibit a stage of development possessed rather by Oligocene than by later forms.

Leidy[5] has described the species *Rhinoceros hesperius* from materials collected in Tertiary deposits of Calaveras County, California, and referred to him by J. D. Whitney. Teeth of this form, according to Leidy, also approach closely in size the corresponding teeth of *Caenopus occidentalis*. The fragmentary materials at present available do not permit, however, a satisfactory comparison between the Tecuja and Calaveras species.

Measurements of No. 23614

$P^{\underline{1}}$, greatest transverse diameter measured along posterior side	22 mm.
$P^{\underline{1}}$, anteroposterior diameter	*a*22.5
$P^{\underline{3}}$?, greatest transverse diameter at base of crown	*a*40
$P^{\underline{3}}$, greatest anteroposterior diameter	*a*31
$P^{\underline{3}}$, height of crown measured over middle of outer side	25.5

a, approximate.

SCIURID, sp. indet.

This squirrel-like form is represented by specimen 23611 (fig. 6), a fragmentary ramus of the mandible with only $M_{\overline{1}}$ and $M_{\overline{2}}$ preserved. The material indicates a form somewhat larger and heavier than the living *Citellus beecheyi fisheri* from the adjacent region of Fort Tejon. In the fragment of fossil jaw the anterior border of the attachment

[4] Osborn, H. F., *op. cit.*, p. 112, 1898.

[5] Leidy, J., The extinct mammalian fauna of Dakota and Nebraska, etc., Jour. Acad. Nat. Sci. Phila., ser. 2, vol. 7, pp. 230–232, pl. 23, figs. 11–12, 1869.

area for the masseter muscle is more sharply defined than in jaws of the Recent series and forms a V, the arms of which are separated by an acute angle. In jaws of the Recent *Citellus* the anterior border of the masseteric fossa is rounded and the upper portion is not so sharply defined as in no. 23611. In the latter specimen, also, the anterior end of this area extends forward to a point below the middle or anterior end of $M_{\bar{1}}$, whereas in Recent jaws the area reaches to a point below $P_{\bar{4}}$. There appears to be a little variation in forward extension of this fossa in the Recent *Citellus,* but it is always somewhat more advanced than in the specimen from Tecuja Cañon.

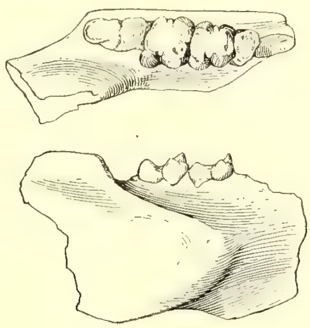

Fig 6. Sciurid, sp. indet. Fragment of mandible with $M_{\bar{1}}$ and $M_{\bar{2}}$, lateral and occlusal views, × 2. Red beds, Tecuja Cañon, California.

$M_{\bar{1}}$ and $M_{\bar{2}}$ are well worn. A small cuspule is present on the inner side of the occlusal surface of each tooth between the anterior and posterior cusps. This cuspule apparently occurs but rarely in the corresponding teeth of the Recent *Citellus* from California.

Age and Relationships of Fauna

From a consideration of the marine invertebrate fauna secured from the upper division of the San Lorenzo in the region west and northwest of Tecuja Cañon, B. L. Clark[6] is of the opinion that a faunal stage is represented which may be younger than that of the Molopophorus lincolnensis zone of the Oligocene of Washington, and is presumably close in its relationship to the fauna of the Agasoma gravidum zone of California as developed in the vicinity of Mount Diablo. It appears evident that the uppermost stage of the marine Oligocene, the

[6] Personal communication.

Acila gettysburgensis zone of C. E. Weaver, is not known to be present in the San Emigdio region, unless the Acila gettysburgensis zone is the correlative of the Vaqueros (Turritella inezana zone).

C. M. Wagner and K. H. Schilling,[7] who have made a special study of the geology and invertebrate palaeontology in the vicinity of San Emigdio Creek immediately to the west and northwest of Tecuja Cañon, determine the unconformable relationship of the San Lorenzo, both to the Tejon Eocene below and to the Monterey Miocene above. At Salt Creek, according to the mapping of Wagner and Schilling, the San Lorenzo deposits pinch out and to the east of this stream, namely between Salt Creek and Tecuja Creek, the basal beds of the Monterey rest directly upon the Tejon.

Overlying the Tejon unconformably in the immediate vicinity of Tecuja Cañon are the red colored deposits or Tecuja beds containing mammalian fossils, which indicate a late Oligocene or early Miocene age for the land-laid sediments. The evidence derived from a study of the geology and invertebrate palaeontology of the area between San Emigdio Creek and Tecuja Creek suggests the possibility that the strata containing the vertebrate remains represents the initiation of a period transitional in time between Oligocene and Miocene. Such a view is perhaps in closest agreement with the known relationship of Lower Miocene and Upper Oligocene vertebrate faunas found elsewhere in North America.

The apparent absence of structural discordance between the red beds and the marine deposits lying immediately above them in the Tecuja Cañon region, together with the fact that the existence of an unconformity has been noted between the Monterey and the underlying Oligocene and Eocene, may permit the assumption that the upper series represents a depositional unit. Should the Tecuja beds be included within the limits of the Monterey Series, the latter would not be characterized by homogeneity of vertebrate faunas, for the mammalian assemblage known from the Merychippus zone of the North Coalinga region[8] is decidedly younger than that from Tecuja Cañon. It is unfortunate that the difference between the two faunas can not be measured in terms of evolutionary stages of the Equidae, for the horse group is as yet unknown in the Tecuja mammalian assemblage. There

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[7] MS.

[8] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga region of California. A contribution to the study of palaeontologic correlation in the Great Basin and Pacific Coast provinces. Trans. Amer. Philos. Soc., vol. 22, pt. 3, n.s., pp. 4–26, 1915.

appears to be some faunal evidence, however, warranting the supposition that the time interval indicated by the difference is such as to be not fully expressed in terms of continuous deposition of a single series of beds. Obviously, if the vertebrates are found to pertain to deposits not included within basal strata of the Monterey Series, the latter group must then be assigned to an age later than uppermost Oligocene or lowermost Miocene.

TABLE GIVING POSITION OF TECUJA FAUNA WITH REFERENCE TO MIOCENE AND OLIGOCENE FAUNAS

GEOLOGICAL PERIODS	PACIFIC COAST MARINE PROVINCE			GREAT BASIN PROVINCE	GREAT PLAINS PROVINCE
	Formations	Vertebrate fauna	Invertebrate fauna		
Miocene	San Pablo			Barstow	Santa Fé
	Monterey	Merychippus zone	Turritella ocoyana	Mascall and Virgin Valley	Deep River
	Vaqueros		Turritella inezana		Lower Harrison Lower Rosebud
Oligocene		Tecuja or Sespe?		John Day	Brule
	San Lorenzo		Agasoma gravidum		
					Chadron

Two marine invertebrate assemblages, namely the Turritella ocoyana fauna and the Turritella inezana fauna, are associated with the Monterey Series in California. The invertebrate remains known from strata above the red beds with mammalian fossils in the Tecuja Cañon area are presumably indicative of the T. inezana fauna. Should the latter zone be actually represented in this region, the vertebrates, found in sediments which apparently exhibit no discontinuity with the overlying marine deposits, may be regarded as yielding evidence in support of a current belief among investigators that the Vaqueros is both a stratigraphic and a faunal unit distinct from the Monterey.[9]

The relation of the red beds containing the vertebrate remains in the Tecuja Cañon region to the overlying Monterey marine deposits, presumably with a Vaqueros fauna, is similar to that which the Sespe formation at the type locality on Sespe Creek, Ventura County, Cali-

[9] Loel, W. F., The Vaqueros formation in California, Abstract in Proc. 8th Ann. meeting of Pacific Coast Branch, Paleontological Society, 1917, Bull. Geol. Soc. Amer., vol. 29, p. 165, 1918.

fornia, bears to the Vaqueros. The position of the Sespe in the Tertiary sequence of California has long been a matter of contention among western geologists and palaeontologists. Within recent years, however, this formation, occupying a stratigraphic niche between the Eocene and the Miocene, has come to be referred to the Oligocene. The relationship which the Tecuja beds show to the Monterey and the lithological characteristics of the red beds themselves, suggest strongly a contemporaneity of deposition of the Tecuja beds and a part of the Sespe at the type locality. While such a view may be held tentatively, a definite assertion can not be made until a vertebrate fauna is obtained from Sespe deposits in the type section.

DESCRIPTION OF LOCALITIES

3352. Red beds exposed in gully immediately behind ranch house on southeast side of Tecuja Creek. NE ¼ of SW ¼, Sec. 25, T. 10 N, R. 20 W. M.D.B. and M. Tejon Quadrangle.

3353. Red beds exposed west of ranch house on Tecuja Creek and northwest of creek. N ½ of SE¼, Sec. 26, T. 10 N, R. 20 W, M.D.B. and M. Tejon Quadrangle.

3354. Red beds on east side of first principal tributary of Salt Creek from mouth. On east section line of NE¼, Sec. 27, T. 10 N, R. 20 W, M.D.B. and M. Tejon Quadrangle.

3356. Third gully below ranch house on southeast side of Tecuja Creek and toward its mouth. SW ¼ of NE ¼, Sec. 25, T. 10 N, R. 20 W, M.D.B. and M. Tejon Quadrangle.

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EXTINCT VERTEBRATE FAUNAS OF THE BADLANDS OF BAUTISTA CREEK AND SAN TIMOTEO CAÑON, SOUTHERN CALIFORNIA

BY
CHILDS FRICK

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CONTENTS

INTRODUCTION

The present contribution is based on the writer's field work in southern California in the late winter and spring of 1916–1917. The investigation was undertaken as a part of the comprehensive plan of the University of California for the study of the geologic and faunal history of the Pacific coast, after consultation with John C. Merriam, Professor of Palaeontology and Historical Geology in that institution.

The region explored was that comprising the two sedimentary areas which lie at the northwest angle of the San Jacinto Range, southern California. (See maps, figs. 1*a*, 1*b*, 1*c*, and views, pls. 43, 44.) These two arid highlands were believed to be land deposits of the late Cenozoic age, but definite evidence as to the stage was lacking.

The first of the two areas is situated within a recess of the San Jacinto foothills, to the northeast of the town of Hemet, in the neighborhood of Bautista Creek. The second lies six miles to the northwest of the first area, near the head of the San Gorgonio Pass, where the main line of the Southern Pacific Railroad climbs from the Colorado Desert through the San Bernardino and San Jacinto mountain ranges. Inward from the rugged summits of the great fault-scarps, lining the flanks of the ranges which rise to the northwest and southeast of both sedimentary areas, stretch the broad, graded valleys of an old land surface,[1] a high plateau that lies four thousand feet below a second and still older surface delineated in the mountain tops. South and west from the base of the sedimentary hills extends the monadnock-dotted Perris Plain.[2] This is the so-called "Perris-peneplain," which has been hypothetically correlated with a surface that cuts the early Pliocene formation of the Mohave Desert[3] in the Great Basin province, or plateau region, to the northwest. Farther south the once nearby presence of the Pacific Ocean is evidenced by the marine deposits of

[1] Baker, C. L. Notes on the Later Cenozoic History of the Mojave Desert Region in Southeastern California. Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, p. 363, 1911. Physiography and Structure of the Western El Paso Range and the Southern Sierra. *Ibid.*, vol. 7, pp. 117–142, 1912.

[2] Some fifteen years ago a rancher, M. Domingoni, while digging a cattle sink in a corner of the Perris floor in the vicinity of Winchester, uncovered in the gravel of an underground stream some large bone and tooth fragments. Judging from his description, the writer believes that the specimens represented a proboscidean.

[3] Dickerson, R. E. Martinez and Tejon Eocene, and Associated Formations of the Santa Ana Mountains. *Ibid.*, vol. 8, p. 260, 1914. Baker, C. L., Physiography and Structure of the Western El Paso Range and the Southern Sierra Nevada. *Ibid.*, vol. 7, p. 137–139, 1912.

Cretaceous, Eocene, and Miocene time occurring in the present Santa Ana Range, certain old topography[4] of whose crest has been tentatively correlated with the Perris peneplain. Some seventy miles to the southwest of this sedimentary area lies Los Angeles and the well known Pleistocene asphalt deposit of Rancho La Brea. Eastward, within the San Gorgonio Pass, fossil-bearing strata[5] of Mexican Gulf relationship occur, deposited, it is supposed, by a far-flung arm of the Gulf of California.

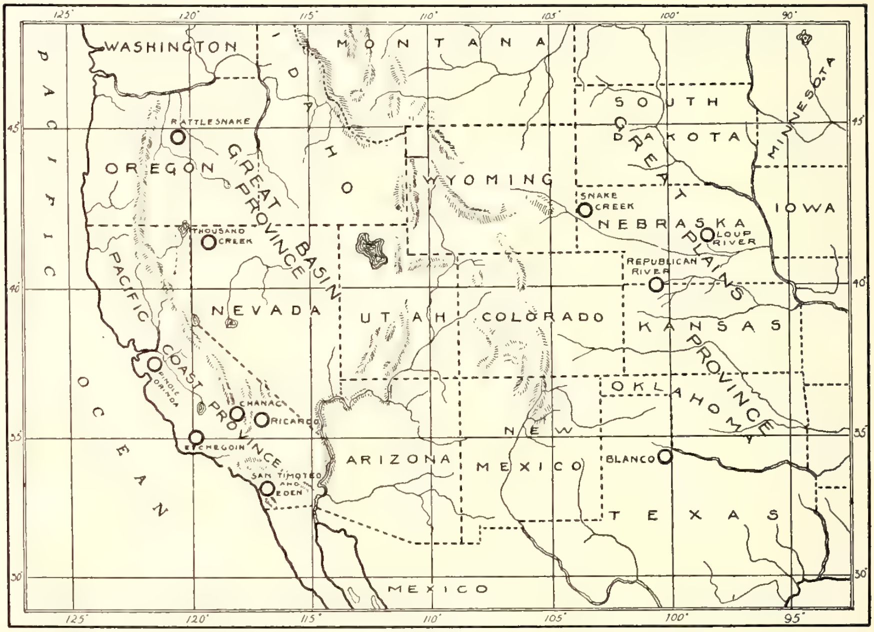

Fig. 1*a*. Map showing the position of the San Timoteo and Eden deposits in relation to the more important of the previously known Pliocene fossil mammal deposits lying west of the Mississippi River.

Bordering as it does on all three of the so-called provinces, viz., the Great Basin, the Pacific Coast, and the Gulf of California, the region occupies a strategic position on the geologic map of California. It is the most southern of the areas from which vertebrate remains have so far been reported from the Pacific slope.

The exploration resulted in discovery of many new and interesting species described in the following pages, and in the recognition and

[4] Dickerson, R. E., *op. cit.*, p. 259, 1914.

[5] Vaughan, F. E. Evidence in San Gorgonio Pass, Riverside County, of a late Pliocene extension of the Gulf of California. Read at the meeting of the Pacific Coast division of the Palaeontological Society in April, 1917.

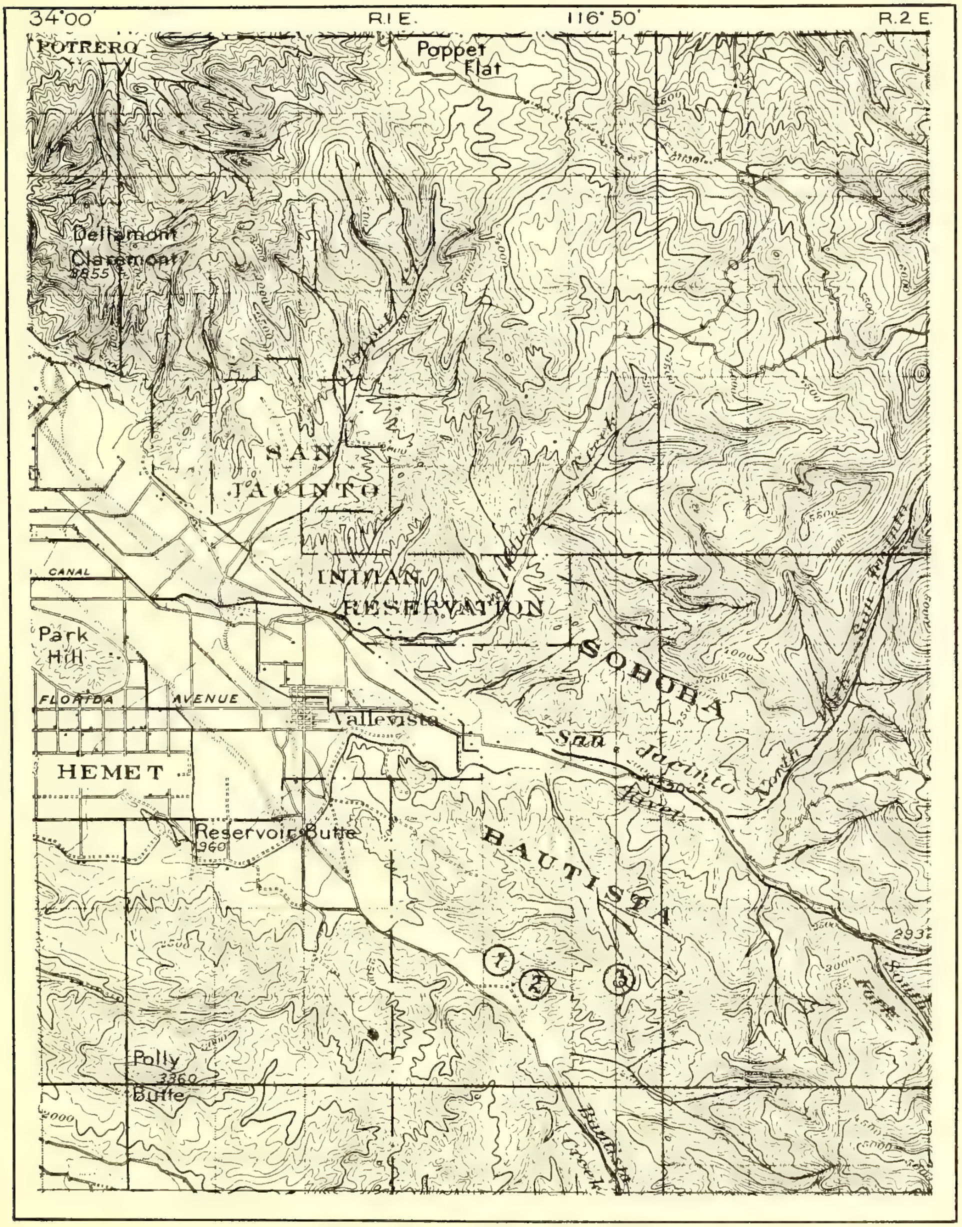

Fig. 1*b*. Section of United States Geological Survey, San Jacinto Quadrangle sheet, showing the Bautista Creek Badlands. Univ. Calif. localities: (1) no. 3240; (2) no. 3247; (3) no. 3243; etc. See list of localities in text, p. 293.

development of three distinct horizons of the late Tertiary and early Quaternary. The determination of the age of these deposits has been especially important in its bearing on the interpretation of local orogenic history and the date of the final elevation of the northwest portion of the San Jacinto Mountain Range, which cannot have been earlier than post-Bautista. The interesting evidence of the fossils is that each of the three new horizons is representative of a faunistic and geographic phase unknown elsewhere.

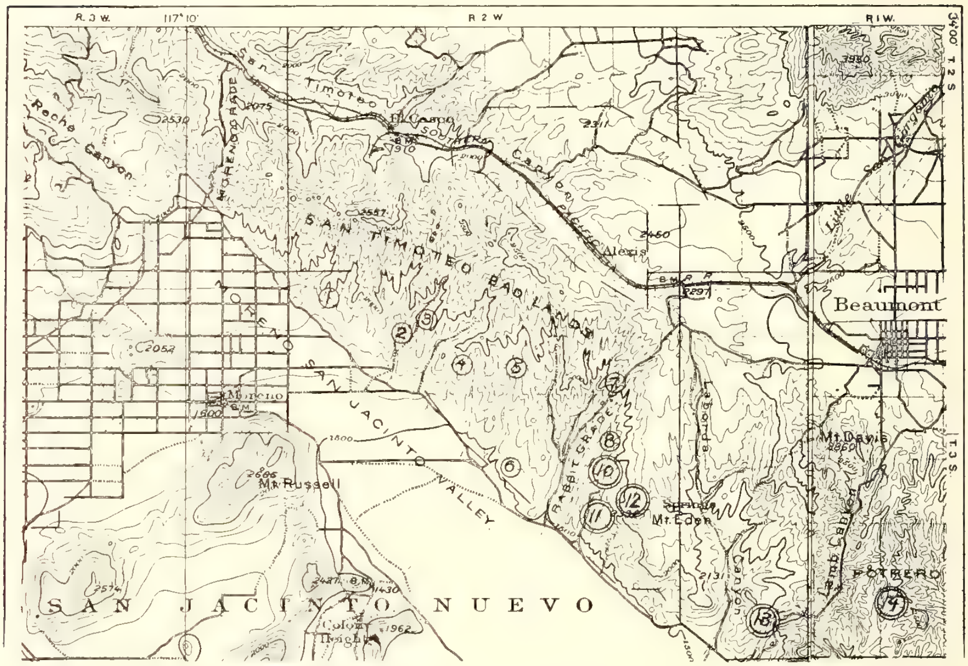

Fig. 1*c*. Section of United States Geological Survey, Elsinore Quadrangle sheet, showing San Timoteo and Eden regions and more important Univ. Calif. localities (San Timoteo, single circles, see p. 319; Eden, double circles, see p. 339). Granitic and metamorphic outcroppings occur about Eden Mountain, Mt. Davis, Lamb Dome, and Potrero Creek.

Among the more important materials secured are: dentitions illustrating new transition stages in the evolution of the horse series from early *Pliohippus* to *Equus;* the molars of a large Pleistocene tapir, and of a great Pliocene bear more closely resembling *Hyaenarctos sivalensis* of the Indian Siwalik than any of the two or three previously represented American forms; remains of four types of ground sloth, and of a number of very interesting varieties of the camel group.

The three exposures and their faunas are as follows:

I. Bautista Creek Area (Pleistocene)

The *Bautista beds,* in which have been found a large *Equus* somewhat resembling that of the Staked Plains, a tapir, a camel, a cervid form resembling *Odocoileus,* a small species of antelope near *Capromeryx,* a neotragocerine-like form, a megalonychid type of ground-sloth, and a rabbit.

II. San Timoteo Cañon Area (Late Pliocene)

The upper series of deposits, here referred to as the *San Timoteo beds,* from which has been obtained a fauna containing a very large and a medium size horse of an interesting *Pliohippus* type approximating *Equus,* a cervid (?), two camels, a megalonychid ground-sloth, and two tortoises.

III. Eden Area (Upper Division of Lower Pliocene)

A lower series of deposits referred to as the *Eden beds,* which has furnished several intensely interesting species of small horse of *Pliohippus* form, fragmentary remains of ground-sloths of megalonychid type, of the sabre tooth tiger, and of small species of dogs and cats, a hyaenarctid bear, several large cervid or antelope-like forms, a smaller antelope, two species of peccary, two giant and three or more smaller varieties of camel, a mastodon of *Trilophodon* type, a species of rabbit, and remains of fish, shells, and wood.

A coarse deposit has been noted underlying the Eden in the neighborhood of Potrero Creek. It has as yet yielded no determinative material.

The immediate aim of the work was originally purely palaeontological, and the geological sketch in the following pages is offered merely as a setting for the description of the faunas, preliminary to the geological mapping of the region.

The writer desires to acknowledge particularly his indebtedness to Professor John C. Merriam for much friendly advice and invaluable assistance in critical determinations.

He wishes also to express his appreciation of the interest shown by Dr. John P. Buwalda in the geological aspect of the problem, and of the great aid rendered by Dr. Chester Stock in assisting in making comparisons with specimens in the University collections, as for his determination of the ground-sloth remains. He would as well acknowledge the painstaking attention of Dr. Stock, Mr. E. L. Furlong, and Miss H. E. Ripley to the manuscript, while in press.

The drawings[6] were made, with great care, by Miss Frieda Leuddemann under the personal supervision of the writer.

The writer would acknowledge the many kindnesses and good will of the owners of the properties where the explorations have taken place, especially Mr. Blackburn, of Hemet, the proprietor of Eden, Mr. Weaver, and many others. He further wishes to draw attention to the enthusiastic coöperation of his field assistant, Mr. Joseph Rak, to whose keen interest and long training as miner and prospector the success in the field was largely due.

HISTORICAL

Palaeontologically up to the time of the present investigation the two regions were virgin territory and unmentioned in the literature. Geologically the San Timoteo Badlands had been interestingly discussed by Dr. W. C. Mendenhall[7] in his study of the water supply of the San Bernardino Valley, in which he points to their great economic importance in forming the impervious southern wall of a natural supply basin. While no vertebrate fossils had been reported from the San Timoteo area at the time of writing, nor previous to the present work, an interesting specimen had been returned from the Bautista deposit. This, the posterior portion of the mandible of a fossil horse containing $P_{\overline{2}}$ and $M_{\overline{3}}$, had been unearthed in the fall of 1916, by Mr. Blackburn, on his fruit ranch, Bautista Creek, Hemet, and sent to the University of California. At the University it had come into the possession of Professor John C. Merriam and had suggested the desirability of an exploration of the neighborhood. At the midwinter meeting of the Pacific Coast section of the Paleontological Society held in April, 1917, the writer read a short report on the work he was then carrying on in this Bautista deposit.

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[6] The sketches were first laid off according to the greatest transverse and anteroposterior measurements; and in the case of shaded drawings these measurements were used as the basis on which to make the slight necessary foreshortening. In the case of the sketches of the occlusal views of the horse teeth all were drawn in the actual plane of the triturating surfaces. The tooth measurements given in the schedules, on the other hand, were taken perpendicular to the tooth axis, and always exclusive of the cement. The anteroposterior diameter is the greatest distance between the anterior and posterior tooth facets in both the upper and the lower teeth. The transverse diameter of the upper equine teeth is the greatest distance between the outer extent of the mesostyle and the inner wall of the protocone; the transverse diameter of the lower teeth is the greatest distance between the inner extent of the metastylid and the outer wall of the protoconid.

[7] Hydrology of San Bernardino Valley, California. U. S. Geol. Surv., Water Supply Paper no. 142, 1905.

HISTORY OF THE REGIONS

California during Pliocene time was very much as today. The land was gradually rising, and on the submerged narrow coastal plain was laid down a great thickness of marine beds.[8] Fortunately for the record of life forms of the time this elevation was not uniform, and through local subsidence older Miocene valleys in the Coast Ranges, sections of the Great Valley, and basins such as that then existing in the region northwest of San Jacinto were filled with land laid sediments.[9]

In the neighborhood of Eden these Pliocene sediments covered the earlier and coarser deposits, such as now seen along Potrero Creek, and buried to a depth of many feet any rough island-like bosses of the older rock that rose above the uneven basin floor, like the present Eden monadnock. The materials of the deposition were fine surface sands and muds derived from the erosion of the granitic and metamorphic rocks of a near-by highland terrane. They were of unassorted finer grades of alluvial material, that point to a development under arid conditions where disintegration was in advance of weathering.[10] They were doubtless spread out as silt over what was then a region of shallow brackish lakes and plains.

It was an interesting assemblage that then roamed the Eden wilds. Grazing over the open stretches were great droves of fleet, light-limbed horses, half a dozen or more species of camels, bands of large and of small antelope, and herds of deer. Within the edge of the scrub might have been seen pigs and larger boar, or an occasional herd of curious, four-tusked proboscideans. In the forests lived sabre-toothed cats, ground-sloths, wolves, and huge bears larger than the largest Kadiak of today.

In richness and variety this extinct American fauna must have compared well with the existing African, the bovid antelopes in their multiplicity of form and the herds of zebra of present Africa recalling

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[8] Smith, J. P. Geological History of California. Science, n.s., vol. 30, p. 346, 1909.

[9] The length of the Cenozoic Era, the Age of Mammals, has been placed, through computations based on the total thickness of sedimentary rocks compared with present ratios of accumulation, at about three million years (Dana, 1874, Walcott, 1893). The last sixth of this period, or 500,000 years, is accepted as the length of the Quaternary (see Osborn, ''The Age of Mammals'' and ''Men of the Old Stone Age''). According to the same reasoning the duration of the Pliocene would have been from 750,000 to 1,000,000 years, which would place Eden age, late Lower Pliocene, in the neighborhood of 1,000,000 B.C.

[10] The analysis of rock specimens was very kindly carried out for the writer by Professor G. D. Louderback.

to a marked degree the camel and equine hosts of our Pliocene of long ago. Moreover, the conditions of this Pliocene were probably very similar to those extant throughout a vast expanse of the desert-encircled belt of the eastern highland of present Africa, where a slight change in altitude with accompanying increase or decrease in humidity, temperature, and vegetation, again and again witnesses the strangest and most marked faunistic change. It may well be that some of the gaps that seem to separate our few known Pliocene assemblages are the result of such local distribution rather than of great lapse of time.

At length local stream activity, stimulated through the gradual elevation of the San Jacinto region, brought the Eden sedimentary stage to an end, and caused its deposits to undergo a period of erosion. This stream rejuvenation may have been due in part to an associated subsidence of adjoining areas, as bedrock, which must in comparatively recent times have been subjected to aërial action, occurs today only at some thousands of feet beneath the floors of adjacent valleys.

At the close of the Eden erosion stage another but coarser series of sediments were laid down, those of the San Timoteo beds. These covered the finer Eden to a great depth. A striking character of this later deposition is the banded appearance of the strata, due to recurring coarser and finer materials, which suggest either alternations of high and low relief or climatic change. The fauna of the time in comparison to that of the Eden is little known, but was evidently of most instructive transitional stage. The small and earlier types of *Pliohippus* are replaced by more advanced horses; a large horse, and a smaller animal that to a pronounced degree resemble the more progressive horses of the older Eden race. Ground-sloths, several camels, antelope, and great tortoises are all represented in this fauna.

The deposits of the Bautista Badlands, lying to the southwest of Eden, are of later date. They were evidently accumulated in part in a playa-like lake as a series of fine, worked-over fanglomerates and clays derived from the low highlands of the immediate north and east. The late Pliocene inhabitants of San Timoteo had in their turn passed away, for in this great deposit are seen collected the remains of a new fauna, though again of mixed forest- and plains-grazing type. The horse is fully as advanced as that which occurs in the Rancho La Brea asphalt deposits, and perhaps with the associated antelope, deer, camels, and ground-sloth represents even a slightly later stage than that indicated by the Rancho La Brea fauna.

FOLDER 1.

A Correlation of the Eden, San Timoteo, Bautista, and Certain Other Horizons. Based on the Characters of Equine Cheek Teeth (see p. 287)

(Relative stages indicated by letters, *a*, *b*, *c*, etc.)

Pacific Coast Province		*Great Basin Province*	*Eastern and Atlantic Area* (*a*)
		California, Oregon, and Idaho (*c*) Equus pacificus Leidy Equus idahoensis Merriam	Equus complicatus Leidy Equus fraternus Leidy
Bautista Creek (*bb*) Equus bautistensis, n. sp.	Rancho La Brea (*d*) Equus occidentalis Leidy		*Great Plains Province* (*b*) Loup River, Nebraska Equus excelsus Leidy Equus niobarensis Hay Staked Plains, Texas Equus scotti Gidley
	Upper Etchegoin (*f*) Pliohippus proversus Merriam		
San Timoteo Pliohippus francescana, n. sp. Pliohippus francescana minor, n. subsp.			Blanco, Texas Pliohippus simplicidens (Cope) Pliohippus cumminsii (Cope)
Eden (*a*) Pliohippus osborni, n. sp. Pliohippus osborni, sp. A, n. subsp. Pliohippus edensis, n. sp. Pliohippus edensis, subform A, Pliohippus, spectans-like Pliohippus edensis, subform B, Pliohippus, indet. sp.	Middle Etchegoin (*d*) Pliohippus coalingensis Merriam	Rattlesnake (*c*), and Thousand Creek (*b*) (*c*) Pliohippus, near fairbanski Merriam (*b*) Pliohippus fairbanksi Merriam (*c*) Pliohippus spectans Cope (*c*) Hipparion, near occidentale Leidy (*c*) Hipparion sinclairi Wortman (*c*) Hipparion, near anthonyi Merriam (*b*) Neohipparion leptode Merriam	Snake Creek, Nebraska (*e*) Pliohippus cf. mirabilis Leidy Pliohippus leidyanus Osborn Hipparion cf. occidentale Leidy Hipparion gratum Leidy Hipparion cf. affine Leidy Protohippus cf. placidus Leidy Protohippus near perditus Leidy
	Lower Etchegoin Pliohippus, sp. Protohippus tehonensis Merriam Hipparion gratum tehonense Merriam Hipparion, near molle Merriam	Ricardo Pliohippus tantalus Merriam Pliohippus fairbanski Merriam Pliohippus, near mirabilis Leidy Hipparion mohavense Merriam Hipparion mohavense callodonte Merriam	

The last stage here recognized was finally brought to a close by a general elevation which, according to the fauna, took place not earlier than mid-Pleistocene time. It lifted the lower San Bernardino and San Jacinto ranges to their present great elevation, and raised and tilted the sedimentary beds of the adjacent basins whose eroded remnants today form the Badlands of the San Timoteo Cañon and of Bautista Creek.

CORRELATION

Eden.—The Pliocene has been the least known of American Tertiary horizons. Only in recent years has a representative fauna been obtained, and the line of division between it and the Miocene can as yet be but loosely drawn. In a recent review Professor J. C. Merriam[11] has grouped the most important Pliocene land-laid deposits according to the topographical features of the Cenozoic Epoch as follows: (1) the Eastern Coast area, represented principally by the Florida Alachua; (2) the Western Plains region, including the early Republican River deposits of northwestern Kansas, the Snake Creek of western Nebraska, and the later Blanco of northwestern Texas; (3) the Great Basin Province, represented by the Ricardo of the Mohave Desert, the Thousand Creek of Nevada, and the Rattlesnake of Oregon; (4) the Pacific Coast Province, including the Chanac-Etchegoin, and the Pinole Tuff-Orinda. The known deposits of this last province are now increased by the addition of the Eden (see map, fig. 1*a*).

The fauna of the Republican River and the Alachua is believed, because of the large proportion of characteristic Miocene types, to lie near the border line between the Miocene and Pliocene. The presence of Miocene, together with a host of more modern forms, in the great Snake Creek aggregation suggests the interesting possibility that the same may represent more than one stage of Tertiary life. All of the more advanced forms of this great assemblage are recognized in allied species in the Thousand Creek, the Chanac-Etchegoin, the Rattlesnake, and the Eden formations, in all of which the oreodonts and *Hypohippus* forms occurring in the Republican River and the Ricardo, and the more primitive of the forms occurring in the Snake Creek are conspicuous by their absence.

[11] Relationship of Pliocene Mammalian Fauna from the Pacific Coast and Great Basin Provinces of North America. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 421–443, 1917.

A comparison of these five interesting and somewhat similar faunas of the Eden, Rattlesnake, Chanac-Etchegoin, Thousand Creek, and advanced stage of the Snake Creek shows: (1) *Prosthennops.* The Eden species is more progressive than the Snake Creek, and perhaps less so than the Thousand Creek, while a larger peccary species from the Eden, more closely resembling *Platygonus,* suggests a similar form known only from the Blanco. (2) *Procamelus* and *Pliauchenia. Pliauchenia merriami* of the Eden is of more advanced type than any of the evidently earlier Snake Creek camels, which alone are represented in a manner sufficient for comparison. (3) *Proboscidea.* Remains occur in all four horizons, but the material is too scanty for fixed reference. (4) The twisted-horn division of the *Antelopinae.* Represented in the Thousand Creek and suggested in the Rattlesnake, this is absent from the Snake Creek as from the Etchegoin-Chanac and the Eden. (5) *Rhinocerotidae.* The Rhinoceroses are as yet unknown from the Eden alone of these mid-Pliocene horizons, though likewise unrecognized in the earlier Ricardo where their presence would be expected. (6) An important difference in the Eden in comparison to these other formations occurs in the absence of *Hipparion.* (7) *Pliohippus.* Species are present in all four formations. Among the Eden *Pliohippus* forms there is one that greatly resembles *P. spectans* of the Rattlesnake; another of more advanced equine characters than any occurring in the four former horizons; while the *Pliohippus mirabilis* type of the Snake Creek and of the Ricardo and the *P. fairbanski* of the Ricardo, Rattlesnake, and perhaps of the Etchegoin and Chanac, are not represented. This presence of an advanced and interesting form of *Pliohippus* among more generalized *Pliohippus* types, such as *P. spectans,* and the absence of more primitive equine forms is taken to indicate a relative lateness in the Eden fauna. It is on these advanced characters of the *Pliohippus* forms, the added evidence of a later stage suggested through the absence of *Hipparion,* and the general progressive characters of the fauna as a whole that the writer has proposed the correlation of the Eden fauna with those of other Pliocene horizons shown in attached table, in which the correlation of the Ricardo, Etchegoin and Chanac, Rattlesnake, and Snake Creek follows that already proposed by Professor Merriam.

San Timoteo.—The horses of the overlying San Timoteo, as described and discussed at length in the text, are perhaps more like *Pliohippus cumminsii* and *Pliohippus simplicidens* (Cope) of the Blanco, which are unfortunately but poorly represented for

comparison, than any one of the other known forms. They are evidently of more primitive type than such species as *Pliohippus proversus* Merriam of the Upper Etchegoin and *Equus idahoensis* Merriam of the probably still later Idaho formation.

Bautista.—The tooth pattern of *Equus bautistensis* suggests a greater degree of specialization than that seen in *E. occidentalis* of La Brea. The teeth while markedly smaller than the type specimens of *E. pacificus* and *E. giganteus*, are very similar in both size and pattern to the teeth of *E. niobarensis* of Nebraska and apparently to those of *E. scotti* of Texas. They are much less specialized than the specimens representing the types of *E. complicatus* and *E. fraternus* Leidy.

PLEISTOCENE FORMATIONS OF THE BAUTISTA CREEK BADLANDS

The Bautista Creek Badlands (fig. 1*b*) lie within the foothills of the San Jacinto Mountains some six miles to the southeast of the badlands of the San Timoteo Cañon. They comprise two large, hilly areas divided by the westwardly flowing San Jacinto River. The more southern area includes the Bautista type locality and stretches six miles southeast between the converging San Jacinto River and Bautista Creek to the igneous wall of the mountainous foothills. At places along this southeastern line of indefinite north and south contact with the basement mass the brush grown sedimentary hills rise to an altitude of 3500 feet. The northern boundary of the Bautista type area and the southern boundary of the second, or Soboban area, is formed by the river. The former unity of both the north and south sedimentary areas is well indicated by the general similarity of the bedding on either bank of the San Jacinto River. A sedimentary remnant, Park Hill, lying immediately to the northwest in the Hemet plain, may belong to the Bautista, and the present isolation may be due to the cutting of the river or its tributaries. The beds forming the Bautista type locality are bounded on the south by the creek of like name and by Rouse's Creek, which joins it from the southeast. The two streams follow the line of contact between the sedimentary deposits and the basement rock, which is believed to mark a fault. An interesting contact between the formation and the basement complex may be seen on the right bank of the San Jacinto River, just west of the mouth of South Fork, where gently north-dipping Bautista sediments rest upon steeply pitching granites (pl. 43, lower

left corner of fig. 1). No clear plane of meeting of basement complex and sedimentary deposit is observed in the wall of Rouse's Cañon to the southeast, the stream cut, which there follows the line of division, running within the fill of a previously excavated channel.

The Soboban portion of the deposit is limited northward by the metamorphics of Claremont and San Jacinto, where the sedimentary beds are faulted down against the side of the mountain. In places they lie directly beneath great, slickensided faces. At least two fault lines occur: that of the main northwest and southeast Claremont fault, mentioned below in conjunction with the hypothetical southern Badland-Eden Mountain line; and a fault running northeast that cuts the first at an angle of 45 degrees and forms the southeast corner of Mount Claremont. The sedimentary beds of the northeast corner of the Sobodan exposure in the immediate vicinity of the fault dip away from the granites, while those a short distance south, along the plane of contact, dip in the opposite direction. This northern dip has again been noted in the poorly stratified exposure of the river bank, and is believed to be the one general to this part of the formation. The structure of the loosely piled deposit, however, shows the results of many violent stresses and is far from uniform. An apparent unconformity in a cliff of coarse, slightly indurated sand at the mouth of Poppet Creek is believed to represent merely an exceptional example of the general disturbance. At this point a large section dipping 15 degrees to the south-southwest apparently rests on another that dips 75 degrees to the south-southeast.

The principal exposure of the Bautista in which collections were made by the writer was the southeastern third of the more southern area, and is known as the type locality (pl. 44, figs. 1, 2). It is bounded on the south by Bautista Creek and on the north by the sedimentary wash of Whittier Cañon that roughly parallels the latter at a distance of a mile and a-quarter. It includes the whole eastern half of the southern portion of the deposit. The beds lie in a twisted and broken fold, whose generalized axis stretches northwest and southeast in line with Park Hill and the so-called Bald Mountain; the dips of the north and south limbs in passing from east to west twist respectively from northeast and southeast to northwest and southwest. The bedding planes, like those of the Soboban exposure, indicate the warping that the whole lightly indurated region has suffered, their continuity being tremendously broken and confused through local faults and slides. A modern and very interesting example of a great slide is to be seen at the northern end of Whittier Cañon, a result of the San Jacinto-Hemet

earthquake of Christmas morning, 1900, when a great bend in the hills a mile and a half across gave way and filled the air of the whole countryside with dust clouds. The vertical displacement of some seventy feet is clearly marked in the surrounding walls. Over the tumbled area the old vegetation grows unharmed. A forester's trail which formerly crossed this area is now forced to a wide detour to the east.

The materials of the Bautista deposit are markedly different from those of the San Timoteo to the northwest, in the evenness of the bedding and in the total absence of cobble-bearing strata. Moreover, the minutely classified strata of fine lacustrine sands and lustrous clays which are present in the main central and higher portions of the type locality are quite unknown in either of the San Timoteo horizons. It is in these clays and fine sands that the best of the Bautista fossil material has been secured. Another difference between the western and eastern areas is the frequent occurrence in the Bautista of concentric sections of calcareous pipes, which range in size from the diameter of a twig to that of a large oak, and point to the former prevalence of hot springs. Mica and gypsum are also more common in the Bautista than in the San Timoteo or the Eden. The surface of the ground itself shows a further difference, the coarse hard litter of quartz gravel and granite cobbles of the San Timoteo being replaced by the disintegrating remains of interstratified calcareous layers.

Conditions suggest that: (1) these great southwestern deposits were derived from erosion of a neighboring highland, in part through a process of weathering such as that now going on in the interesting granitic faces at the head of Rouse's Cañon, which are indistinguishable at short distances from the whiter sand bluffs of the sedimentary areas; (2) the materials of erosion were accumulated on an old land surface crossing the basement complex, and were later raised and faulted down, as indicated by the general plane of contact between the north and south boundaries of the sediments and the granites, as well as by such visible points of deeper meeting as that at the mouth of South Fork.

Occurrence

The present day surface of the Bautista deposits offers a considerably richer field for the collection of fossils than either the San Timoteo or the Eden. Mr. Blackburn found the original equine mandible within a recently burnt-over area at the mid-southern extremity of the typical exposure, where careful examination of the

top soil and the washes later revealed further interesting material. Fossils have been found in place in the following sediments:

1. Nodular, indurated, sandy clays: In tracing the source of fragments of bone and digging within the top soil small pockets have been located containing nodular sandy clay rock, reddish tinged on fracture, and holding associated skeletal remains. The rocks lay in a stratum of fine sandy, micaceous clay, which farther down contained less clay and more sand, and at slightly lower levels passed into grayer and coarser sand. At one locality (3242) three such pockets occurred within a radius of twenty feet, containing equine limb bones that had apparently belonged to the same individual. The manner of occurrence, and the fact that certain separated nodules contained parts of the same bones, the broken silicified edges of the bones matching when brought together, evidence that considerable movement has occurred in the deposit since the time of deposition and nodularization.

2. Thick deposits of black clay: Within the south-central part of the Bautista district, at twenty-five hundred feet elevation, are considerable northeast-dipping deposits of lustrous black, micaceous clays alternating with fine sands. Similar beds have been noted dipping to the southwest in a ravine eight hundred feet lower down. At one place at the higher elevation these clays were found to contain many bone fragments, and here (locality 3243) much of the most representative Bautista material was obtained. The operation was carried on in a four-foot stratum that was interbedded between layers of coarse, gray sand. Above the latter was another layer of the clay a foot in thickness, and this was overlain by coarse, yellowish sand, which higher up became grayer and was mixed with quartz pebbles. The fossils though comparatively plentiful were soft, and were minutely broken from the gradual movement evidenced in the network of cracks that ran throughout the entire deposit.

3. Fine and coarse, non-indurated sands: Fossils were found to a somewhat less extent in the non-indurated sand beneath these clays. Exposures of micaceous, fine, greenish sand, rather frequent throughout the southwestern portions of the Bautista, have also yielded considerable material, especially in the neighborhood of calcareous ledges. The original equine jaw fragment was found by Mr. Blackburn in such a formation (locality 3240).

4. Exceptionally, in fine, brown-gray, micaceous sandstone: A piece of this rock picked up at the mouth of one of the cañons yielded a well preserved fragment of the mandible and teeth of a small artiodactyl.

BAUTISTA FOSSIL LOCALITIES WHERE MORE IMPORTANT SPECIMENS WERE COLLECTED

All localities, unless otherwise stated, are in T. 5 S, R. 1 E., San Bernardino B. L. and M., San Jacinto Quadrangle, U. S. Geol. Surv. Sheet (fig. 1*b*)

	Univ. Calif. loc.	
Fossil Cañon	3240	SE portion NW ¼ of SW ¼ of Sec. 26, W side, first small wash on SW side of burnt hills and E of North Cañon; barometric altitude 2200 feet. (fig. 1*b*, no. 1.)
Horse and Deer Pits	3421	S portion NE ¼ of SW ¼ of Sec. 26, W running ridge E and NE of Fossil Cañon Deer-pit 200 yds.; W and below Horse-pit.
Pedata Pit	3242	S portion NW ¼ of SE ¼ of Sec. 26, Hog-back on north side, ¼ mile up sixth easterly cañon above mouth of North Cañon.
Blacksand Station	3243	S portion SW ¼ of SW ¼ of Sec. 25, 40 ft. cut in ridge corner; barometric altitude 2820 feet. (fig. 1*b*, no. 3.)
Blacksand Top	3244	Ridge directly above and N of station 3243.
Slide Region	3245	W portion SE ¼ of SE ¼ of Sec. 25, 40 ft. cut in ridge corner; barometric altitude 2950 feet.
Highest Hill	3246	SE ¼ of SW ¼ of Sec. 30, T. 5 S, R. 2 E.
Meek's Neighborhood	3247A	Small cañon and low ridges in immediate vicinity of old house foundations. (fig. 1*b*, no. 2.)
Whittier Cañon	3247B	Mouth of cañon bounding type locality to W and NW.

DESCRIPTION OF BAUTISTA PLEISTOCENE FAUNA

Lepus, sp.
Megalonyx, sp.
Camelid
Odocoileus(?), two or more species
Capromeryx(?), sp.
Antilocapra or Neotragoceros, one or two indet. sp.
Equus bautistensis, n. sp.
Tapirus merriami, n. sp.

LEPUS, sp.

Material.—Two fragments of calcaneum and podial bone, Univ. Calif. Coll. Vert. Pal. no. 23522, Univ. Calif. loc. 3247B.

The small specimens give evidence of the presence of a fair-sized rabbit or hare in the Bautista fauna, but are too fragmentary for specific determination.

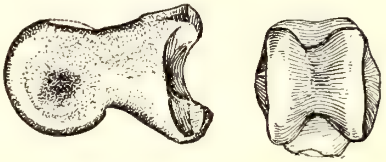
MEGALONYX?, sp.

Material.—The phalanx of a ground-sloth, Univ. Calif. Coll. Vert. Pal. no. 23372 (figs. 1*d* and 1*e*), Univ. Calif. loc. 3243.

Measurements

	No. 23372
Greatest anteroposterior length	54.5 mm.
Greatest dorsoventral depth of proximal end	36
Greatest transverse thickness at middle	33.5

The specimen (fig. 1) is of nearly bilateral symmetry; the proximal articulation consists of two vertical concavities separated by a median ridge, the upper and lower extremities of which are of nearly equal


1d 1e

Figs. 1*d* and 1*e*. *Megalonyx?*, sp. Second phalanx, no. 23372, × ½. Fig. 1*d*, lateral view; fig. 1*e*, distal view. Bautista beds, California.

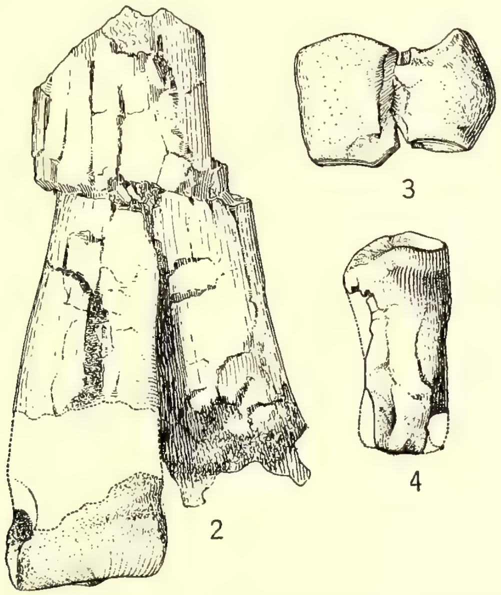
size and production; the convex borders of the distal trochlea describe approximately two-thirds of a circle, the groove of the trochlea is very deep.

Remains of both the genera *Nothrotherium* and *Megalonyx* occur in the Pleistocene of Rancho La Brea and in the cave deposits of northern California. Dr. Chester Stock, who kindly has examined the specimen, states that it possibly represents a phalanx of a small megalonychid form. The Bautista specimen is short and slender compared to a phalanx from Hawver Cave which has been tentatively referred to *Megalonyx*. It resembles somewhat phalanx 2, digit 2 of the manus of *Mylodon* from Rancho La Brea but is smaller.

CAMELID?, sp.

Material.—The distal portion of a metapodial, no. 23458; a scaphoid, no. 23396; and two phalanges, nos. 23388–23389, all in Univ. Calif. Coll. Vert. Pal. (figs. 2–4); all from Univ. Calif. loc. 3243.

The metapodial (fig. 2) has been considerably crushed. It is of medium size, and with the phalanges (fig. 4) and scaphoid (fig. 3)



Figs. 2 to 4. *Camelid?*, sp. Limb elements, × ½. Fig. 2, distal portion of metapodial, no. 23458, anterior view; fig. 3, scaphoid, no. 23396; fig. 4, second phalanx, no. 23388. Bautista beds, California.

represents a much smaller form than *Camelops* of Rancho La Brea. The specimen apparently belongs to an individual of much the same size as that represented by a first phalanx in the Univ. Calif. Coll. (no. 10986) from the San Pablo Pleistocene.

MEASUREMENTS

No. 23458, diameter of single distal trochlea of metapodial	39.3 mm.
No. 23458, length of separation between inner and outer trochlea of metapodial	74.8
No. 23388, length of second phalanx	61.5
No. 23388, diameter of proximal end of second phalanx	29.1

ODOCOILEUS?, two or more species

Material.—(1) A section of a left mandible containing the last cheek-teeth, Univ. Calif. Coll. Vert. Pal. no. 23405 (fig. 5), Univ. Calif. loc. 3247A. (2) The proximal half or two-thirds of an antler with burr and prong, no. 23419 (fig. 6), Univ. Calif. loc. 3243. (3) A metatarsus and first phalanx, no. 23452, distal end of first phalanx, no. 23524, and second phalanx, no. 23523 (figs. 7, 8), loc. 3249, (4) A right humerus, associated with portions of the ulna and radius, the metacarpus, a sesamoid, and parts of the left humerus and ulna-head, the radius and the metacarpus, nos. 23442–23445, nos. 23448–23450 (figs. 9–12*b*), loc. 3241. A piece of the distal end of a humerus, no. 23526, from vicinity of loc. 3241. (5) An astragalus associated with the distal end of a left tibia, no. 23401 (fig. 14), Univ. Calif, loc. 3247; a right astragalus, same coll., no. 23402, region of Univ. Calif. loc. 3241. (6) The mid-distal end of a larger humerus, no. 23451; the head fragment of a small femur, no. 23781; the head fragment of a medium sized femur, no. 23782; and the portion of a scapula are all referred to this section. All specimens in Univ. Calif. Coll. Vert. Pal. All Eden localities.

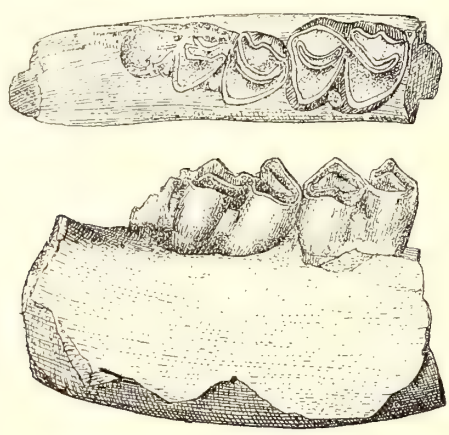


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Fig. 5. *Odocoileus?*, sp. Fragment of mandible with $M_{\overline{3}}$ and $M_{\overline{2}}$, no. 23405, × 1. Bautista beds, California.

The material indicates the presence of two or more *Odocoileus*-like species.

The lower molars no. 23405 (fig. 5) are comparatively light and low-crowned, and the enamel is considerably crinkled. Two outer buttresses, or styles, are present in $M_{\overline{3}}$; a single style in $M_{\overline{2}}$. The teeth differ from those of *Odocoileus hemionus* and *O. columbiana* in the presence of these two outer buttresses in the last molar, as in the development of the single buttress of $M_{\overline{2}}$, which though generally

prominent in the premolars of *O. hemionus* is often absent from the molars of both *O. hemionus* and *O. columbiana.* So far as observable the cervid remains from the Pleistocene cave deposits of California also lack the double buttress of the last molar. The enamel is considerably more crinkled than that of the comparatively long-crowned *O. hemionus,* and somewhat more crinkled than in *O. columbiana.*

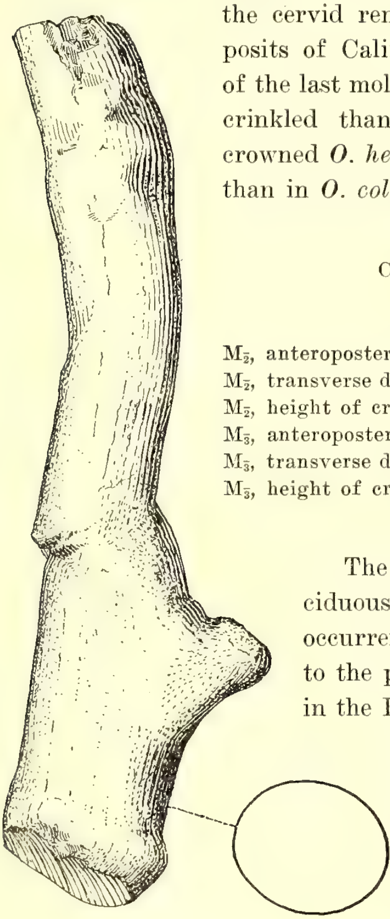

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Fig. 6. *Odocoileus?,* sp. Proximal portion of antler, no. 23419, × ⅔. Bautista beds, California.

Comparative Measurements

	Odocoileus?, sp. no. 23405	O. hemionus	O. columbiana
$M_{\overline{2}}$, anteroposterior diameter	25.8 mm.	23.2	25.2
$M_{\overline{2}}$, transverse diameter	10.3	10.3	8.2
$M_{\overline{2}}$, height of crown	9.1	10.6	11
$M_{\overline{3}}$, anteroposterior diameter	22.2		20
$M_{\overline{3}}$, transverse diameter	9.9		7.2
$M_{\overline{3}}$, height of crown	8.4		10.7

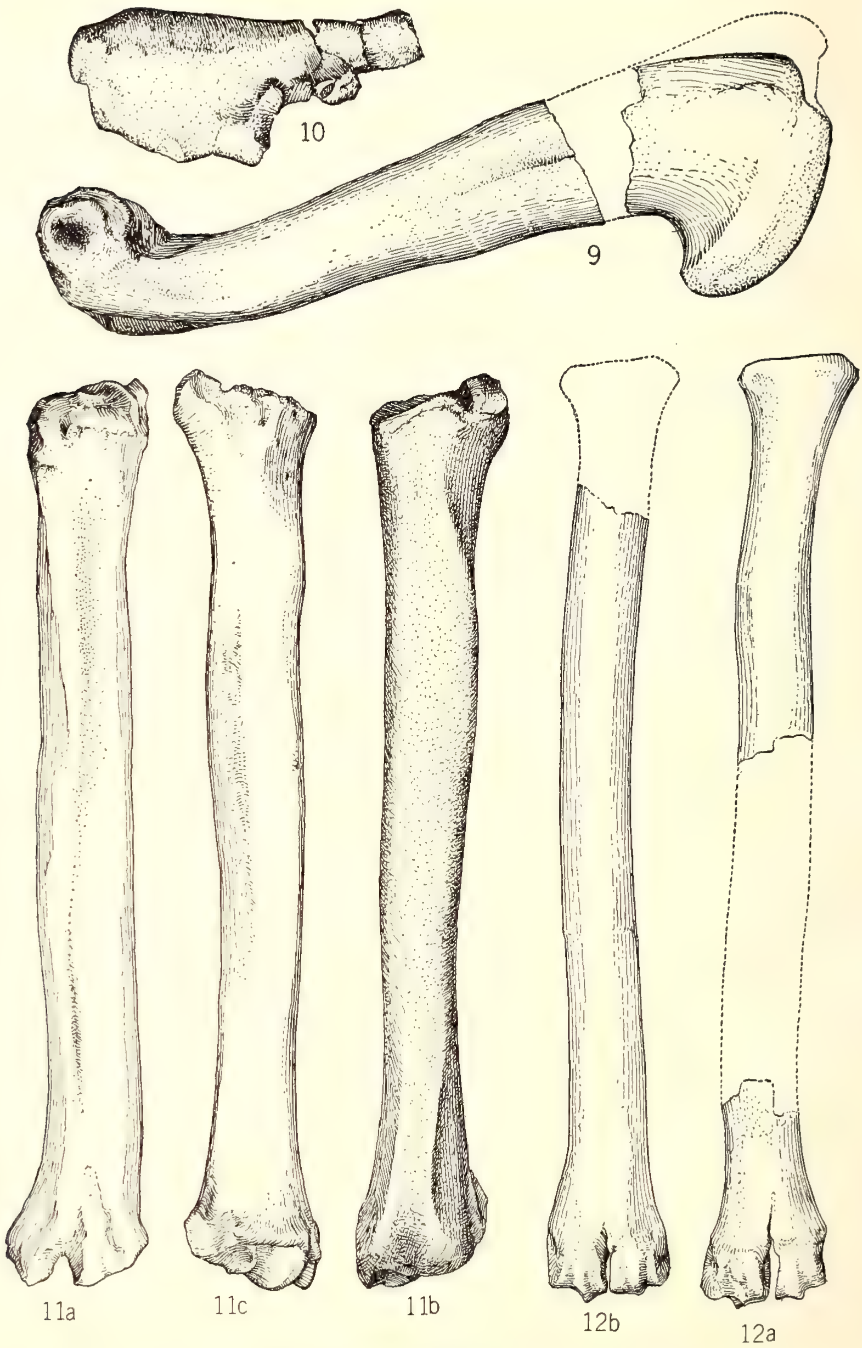
The specimen (fig. 6) represents a deciduous antler of advanced cervid type. The occurrence is of interest as strongly pointing to the presence of a species near *Odocoileus* in the Bautista Pleistocene.

A metatarsus, no. 23452, is unfortunately somewhat crushed. Though slightly heavier proportionately than the metacarpus described below (fig. 12) it is of a very similar appearance. The phalanges (figs. 7, 8) are more typically deer-like than antelope-like in form.

7

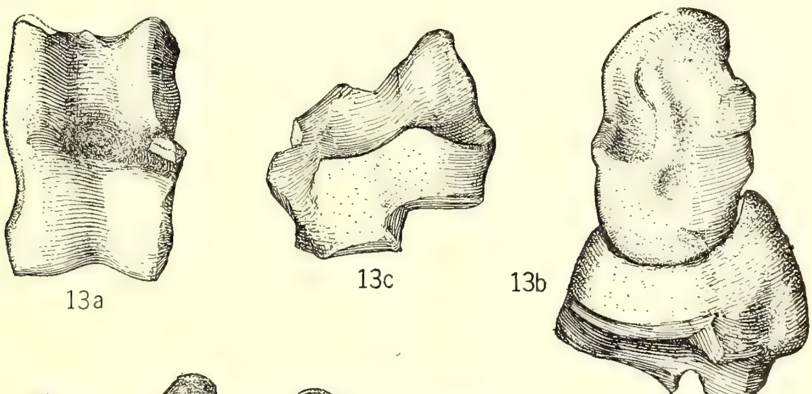
8

Figs. 7 and 8. *Odocoileus?,* sp. Phalanges, × ½. Fig. 7, first phalanx, no. 23524; fig. 8, second phalanx, no. 23523. Bautista beds, California.

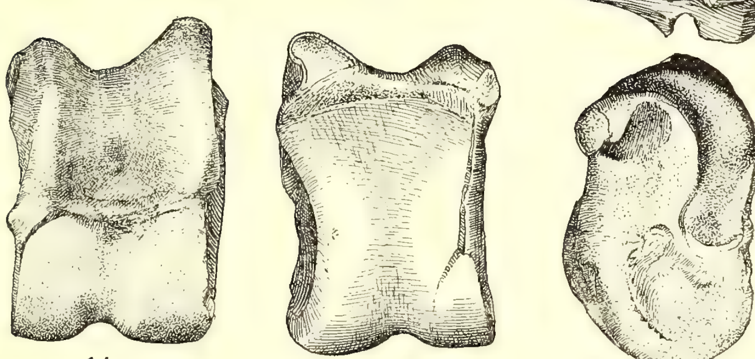


Figs. 9 to 12*b*. *Odocoileus?*, sp. Associated limb elements, × ½. Fig. 9, humerus; fig. 10, proximal portion of ulna; figs. 11*a* to 11*c*, radii; figs. 12*a* and 12*b*, metacarpals. Bautista beds, California. Univ. Calif. Coll. Vert, Pal. nos. 23442–23445 inclusive, and nos. 23448–23450.

The anterior limb elements (figs. 9–12) suggest a form fully as tall but slighter, and longer-shanked than the modern mule-deer. The metacarpus is of very similar form to the metatarsus described above, and may represent the same species. Compared with the corresponding bones of *Odocoileus hemionus:* (1) the humerus (fig. 9) is slightly shorter and lighter; (2) the radius (fig. 11) is slightly lighter and of about equal length; and (3) the metacarpus (fig. 12) is distinctly longer.



13a 13c 13b



14a 14c 14b

Figs 13*a* to 13*c*. Cervid or *Antilocapra?*, sp. Tarsal elements, no. 23403, × 1. Fig. 13*a*, astragalus, dorsal view; fig. 13*b*, astragalus and navicular-cuboid, outer view; fig. 13*c*, navicular-cuboid, lateral view.

Figs. 14*a* to 14*c*. *Odocoileus?*, sp. Astragalus, reconstruction from nos. 23401, 23402, × 1. Fig. 14*a*, dorsal view; fig. 14*b*, lateral view; fig. 14*c*, ventral view. Bautista beds, California.

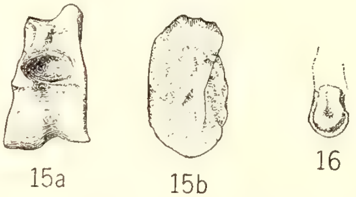
The two astragali (see reconstruction, figs. 14*a*–14*c*) are considerably heavier and of different character from no. 23403 (see above, fig. 13), being strongly cervid throughout in: (1) the groove of the distal end is deep and sharply defined, and the outer condyle of the trochlea broad; (2) the occurrence on either side of the central fossa of a knob which terminates mid-dorsally both condyles of the proximal

trochlea surface, instead of that of the inner side only as in the antelope; and (3) the contour of the outer condyle of the proximal trochlea which is broad and full, while the groove of the wide calcaneal surface is medium and pronounced.

CAPROMERYX?, sp.

Material.—A small astragalus, and a section of the distal end of an associated metapodial, Univ. Calif. Coll. Vert. Pal. no. 23527A (figs. 15, 16), Univ. Calif. loc. 3245.

The astragalus (fig. 15) is considerably broken and worn. It is distinctly smaller than any specimens of *Capromeryx minor* Taylor



Figs. 15*a* to 16. *Capromeryx?,* sp. Astragalus and distal end of metapodial, no. 23527, × 1. Fig. 15*a,* dorsal view; fig. 15*b,* outer view; fig. 16, lateral view. Bautista beds, California.

from Rancho La Brea in the collections of the University of California. It further differs in having a larger and deeper fossa, and in being proportionately broader with the mid-dorsal groove of the proximal trochlea surface more shallow. The specimens suggest the occurrence of a small undescribed species of *Capromeryx,* even more diminutive than the Rancho La Brea form, which represents one of the smallest of Pleistocene ungulates.

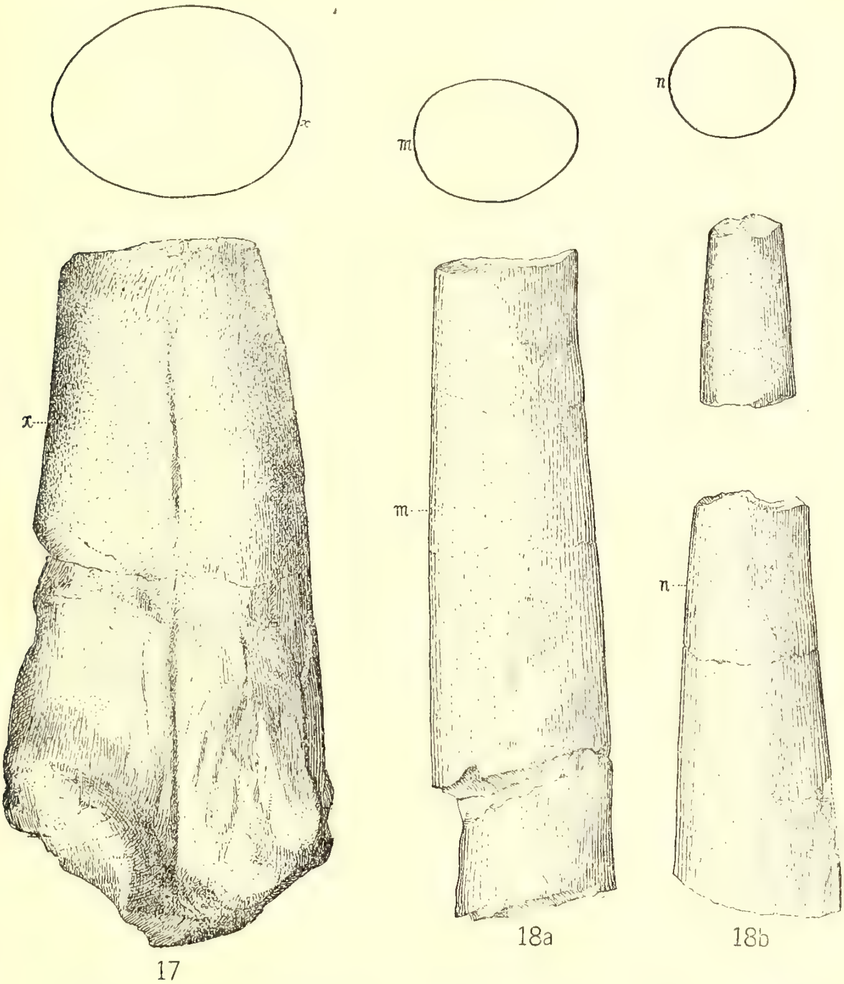
ANTILOCAPRA?, one or more species

Material.—A basal portion of a horn core, no. 23453, and two sections of smaller horn cores, no. 23420 (figs. 17, 18*a*–18*b*), all Univ. Calif. Coll. Vert. Pal., general loc. Univ. Calif. 3247A.

An astragalus, associated with a navicular-cuboid, a cuneiform, and pieces of a calcaneum (figs. 13*a*–13*c*), nos. 24016, 23235, 23759, 23523, 23403, 24017, 23404, Univ. Calif. Coll. Vert. Pal., Univ. Calif. loc. 3243.

Discussion.—The specimens shown in figures 17 and 18 are of the flat-horned antelopine type. They are believed to represent the basal

and distal horn portions of some unrecognized member of the *Antilocapra* or *capromeryx* groups furnished with horns of Old World tragocerine type.



Figs. 17 to 18*b*. *Antilocapra?*, sp. Portions of horn cores, × 1. Fig. 17, no. 23453; figs. 18*a* and 18*b*, two sections, no. 23420. Bautista beds, California.

The astragalus no. 23403 (fig. 13), which is unfortunately somewhat broken, evidences strong cervid relationship, showing dorsally the broad and full cervid-like contour of the outer condyle of the trochlea, as ventrally the wide median grooving of the broad calcaneal surface. The specimen, however, in contradistinction to two slightly larger cervid-like astragali (see above), resembles somewhat more the

Antilocapra type in the character of the median groove of the distal end, which is shallow and continuous with the slope of the adjacent condyle, and in the presence of but the single inner trochlea-knob on the dorsal surface. Furthermore, the posterior facets of the navicular-cuboid articulating with the cuneiform lie at a right angle instead of an acute angle as seen in *Odocoileus.* The calcaneum is lighter and apparently shorter, and the first and second phalanges narrower and considerably lighter than in *O. hemionus.*

EQUUS BAUTISTENSIS, n. sp.

Type.—Three associated premolars from the left side of an upper jaw, Univ. Calif. Coll. Vert. Pal. nos. 23239, 23238, 23245 (folder 2, fig. 1), Univ. Calif. loc. 3243. To this species is referred all of the Bautista equine material, including upper and lower cheek teeth, incisors, and limb elements, as enumerated and described below (figs. 19–25, folder 2, pl. 45).

Referred Material.

Upper cheek teeth: Three molars of the left side of the upper jaw, figured in series with the type premolars, Univ. Calif. Coll. Vert. Pal. nos. 23245, 23246, 23247, Univ. Calif. loc. 3243 (folder 2).

A compiled right series of unassociated teeth from upper jaw, all from the same locality as the type (folder 2, fig. 2), Univ. Calif. Coll. Vert. Pal. no. 23236, Univ. Calif. loc. 3244.

A partly associated series of worn teeth from upper right jaw (folder 2, fig. 3), Univ. Calif. Coll. Vert. Pal. no. 23244, Univ. Calif. loc. 3244.

Lower cheek teeth: A fragment of mandible containing associated lower series (lacking $M_{\overline{3}}$), (figs. 19, 23), Univ. Calif. Coll. Vert. Pal. no. 23196, Univ. Calif. loc. 3243.

Section of a mandible with portions of all the series except $P_{\overline{2}}$ (figs. 21, 24), Univ. Calif. Coll. Vert. Pal. no. 23913, Univ. Calif. loc. 3240.

Various lower cheek teeth (figs. 20*a*–20*c*, 22*a*–22*c*), Univ. Calif. Coll. Vert. Pal. nos. 23241, 23248, 23252, 23250, 23241A, 23249, Univ. Calif. loc. 3243.

Incisors: A set of incisors in a fragment of the premaxillary (fig. 25), Univ. Calif. Coll. Vert. Pal. no. 23348, Univ. Calif. loc. 3243.

Limb elements: A metacarpus (pl. 45, fig. 1), Univ. Calif. Coll. Vert. Pal. no. 23460, Univ Calif. loc. 3245.

The proximal and distal portions of a second metacarpus associated with the first, second, and portion of a third phalanx, unciform, magnum, trapezium, and scaphoid (pl. 45, fig. 2), Univ. Calif. Coll. Vert. Pal. no. 23466, Univ. Calif. loc. 3242.

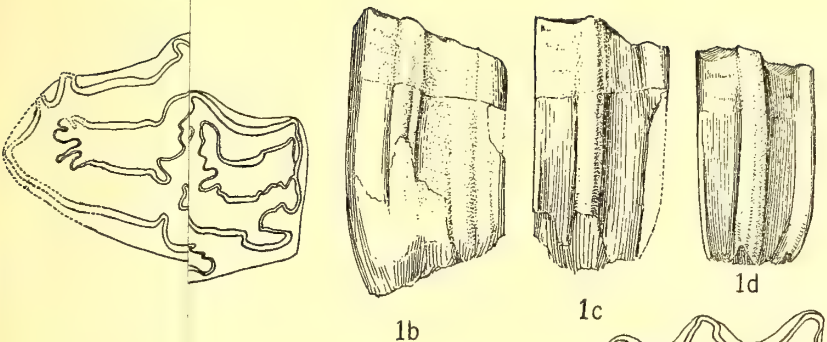
An associated series of bones of the right hind limb from Univ. Calif. locality 3241, as follows:

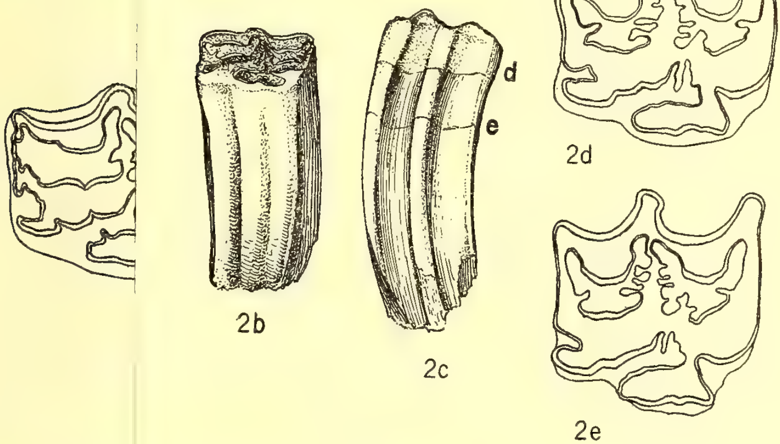
Proximal and distal portions of femur (pl. 45, fig. 6), no. 23489.

Proximal half of tibia (pl. 45, fig. 7), no. 23472.

An astragalus and calcaneum (pl. 45, figs. 3*b*–3*c*), no. 23463.

Third metatarsal with first and second phalanges (pl. 45, fig. 3*a*), no. 23459, Univ. Calif. loc. 3241.





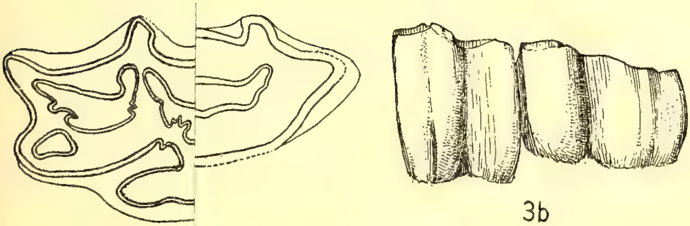
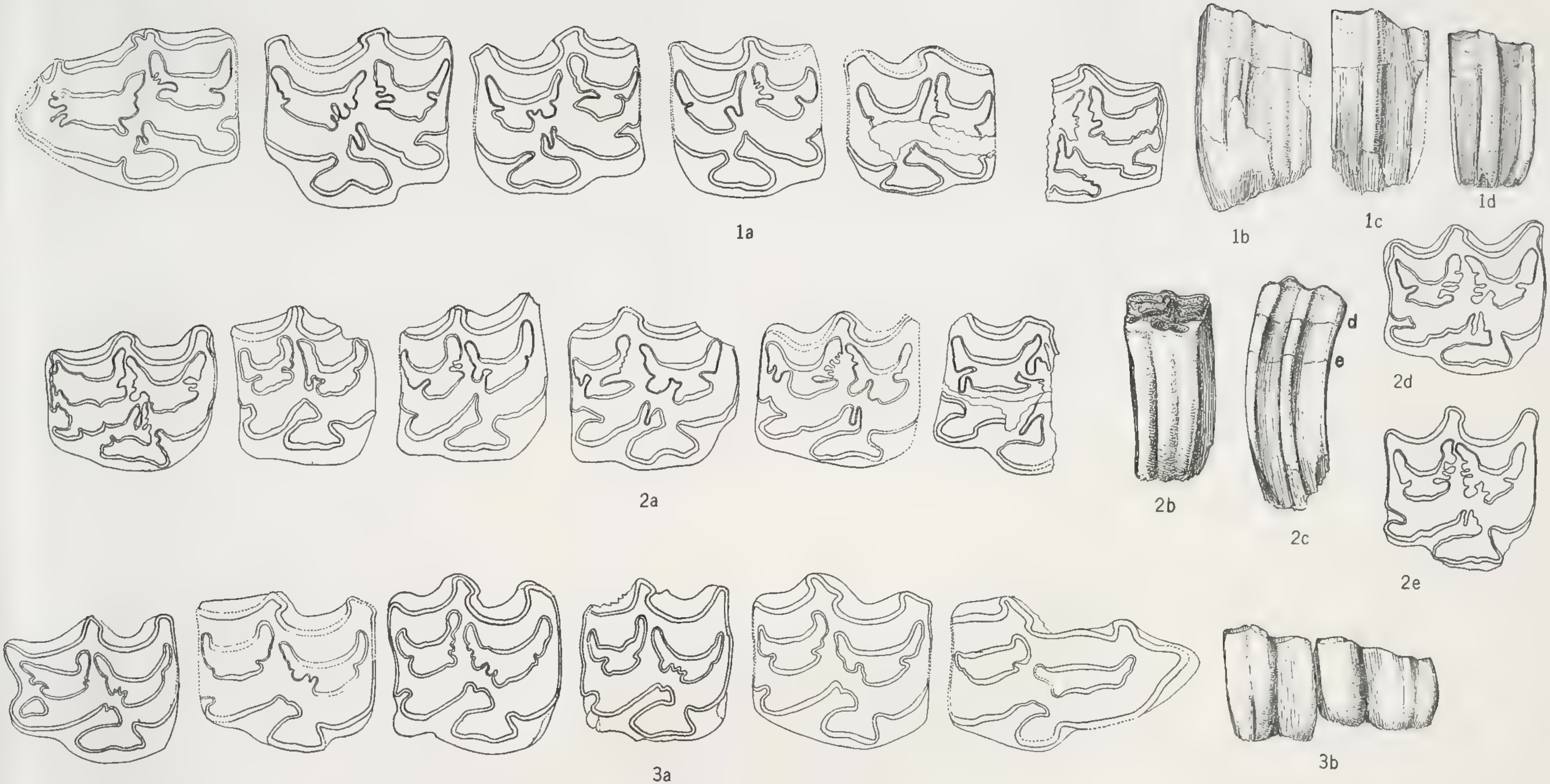


Fig. 1. 3243, 23246, 23247; *a*, occlusal view, natural size; *b*, *c*, *d*, outer aspect

Fig. 2. ect of no. 23236, × ½; *c*, outer aspect no. 23786, × ½; *d*, *e*, cross sec

Fig. 3. of P² and P², nos. 23253 and 23258, × ½. All Univ. Calif. Coll. Vert. P



EXPLANATION OF FOLDER 2

Upper dentition of *Equus bautistensis*, n. sp. Bautista beds, California.

Fig. 1. Associated P^2, P^3, and P^4 of type specimen, Univ. Calif. Coll. Vert. Pal. nos. 23239, 23238, 23245, and referred molars nos. 23243, 23246, 23247; *a*, occlusal view, natural size; *b*, *c*, *d*, outer aspect of the type premolars. $\times$ ½.

Fig. 2. Compiled series of six unassociated teeth, referred to the type; series no. 23236; *a*, occlusal views, natural size; *b*, inner aspect of no. 23236, $\times$ ½; *c*, outer aspect no. 23786, $\times$ ½; *d*, *e*, cross sections at *d* and *e*, no. 23786, natural size. All Univ. Calif. Coll. Vert. Pal.

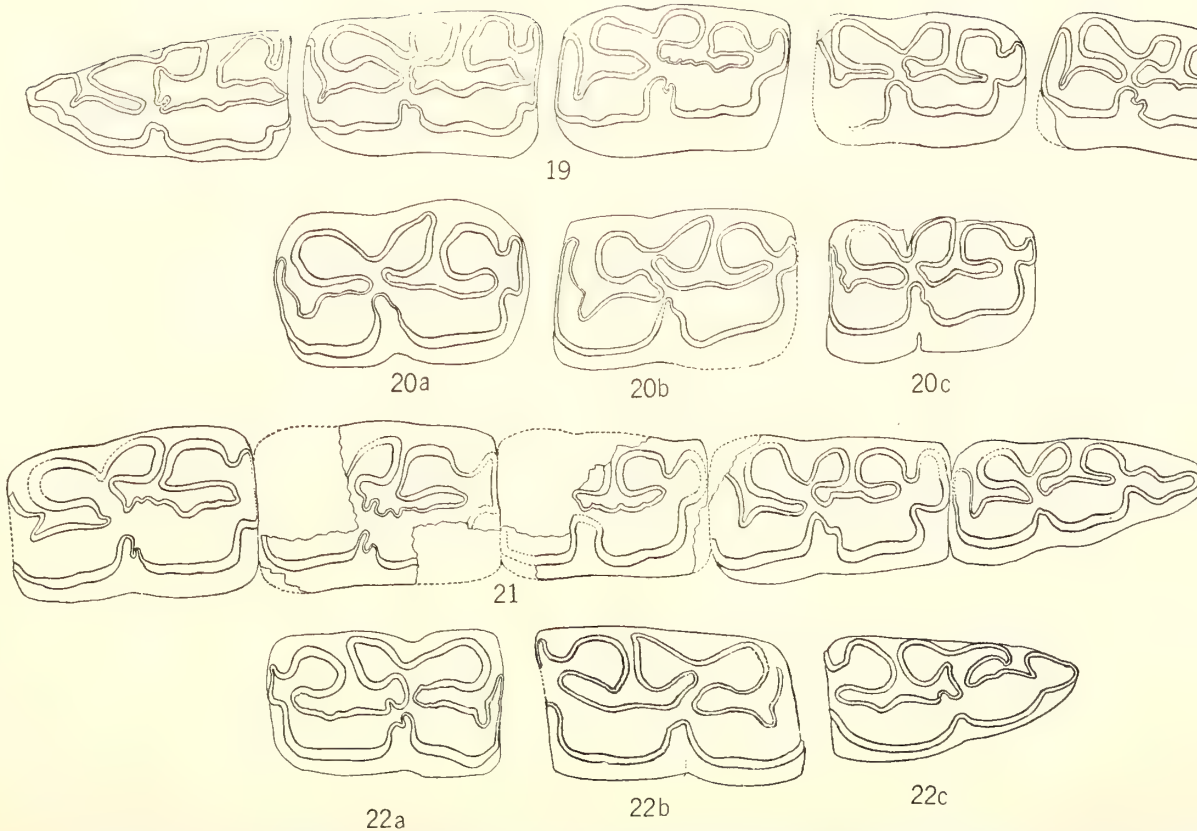
Fig. 3. Partly associated series of much worn teeth, referred to type, series no. 23244; *a*, occlusal view, natural size; *b*, lateral view of P^3 and P^2, nos. 23253 and 23258, $\times$ ½. All Univ. Calif. Coll. Vert. Pal.

The limbs are also represented by material from various localities which conforms with the foregoing:

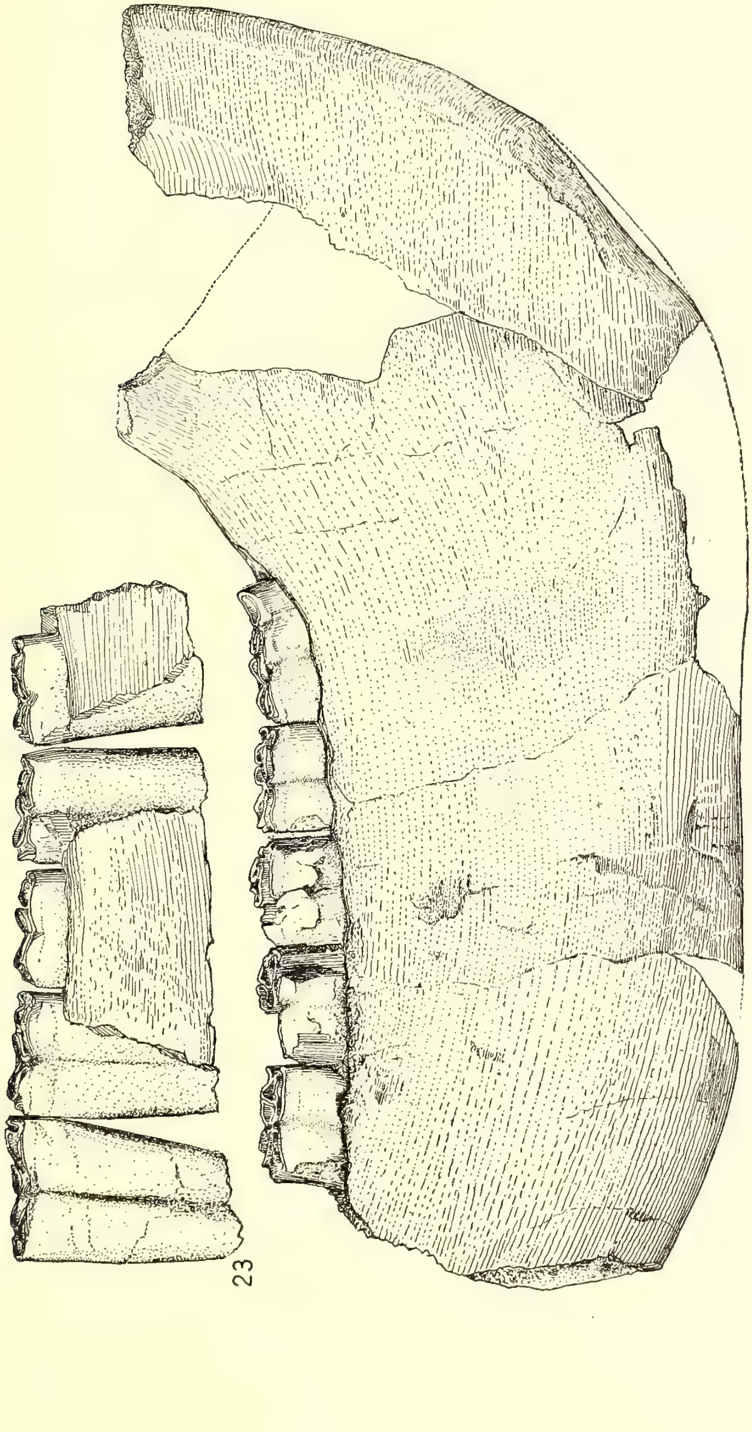
Portions of navicular and cuneiform bones (pl. 45, figs. 4, 5), nos. 23471A, 23765.
Cuneiform, no. 23765.
Portion of cuboid, no. 23766.
Inner pulley of astragalus, no. 23769.
Head and pulley of a metatarsus, nos. 23468 and 23471.
Metapodial pulley and fragment of a second, nos. 23467 and 23468.
Distal portion of a first phalanx, no. 23469.
Second phalanx, no. 23465. All in Univ. Calif. Coll. Vert. Pal. Various localities.

Characters.—*Equus bautistensis* is characterized by: (1) The prominent bilobed form of the anteroposteriorly elongated protocone in the large sized premolar teeth and by the considerable anterior extension of the protocone throughout the series, the protocone averaging longer anteroposteriorly than that of the Rancho La Brea form of *Equus occidentalis* Leidy; (2) the relative amount and complexity of the infolding of the fossette margins, which is less than that seen in certain of the later equines and more than that occurring in *E. occidentalis;* (3) the comparative narrowness in transverse diameter of the referred lower teeth, and the relative flatness of the outer faces of the protoconid and hypoconid; (4) the average sharpness of the gutter of the metaconid-metastylid column, and the considerable prominence of the valley between the protoconid and hypoconid; (5) the depth of the referred mandible viewed laterally, as compared with *E. caballus,* and the relatively slight concavity of the inferior border of the mandible anterior to the angle of the jaw as compared to *E. occidentalis* of Rancho La Brea.

Description.—The upper dentition is of large size. The mesostyle and parastyle of the premolars are relatively broad, in the molar series the styles become progressively narrower. The protocone is large and elongated, the anterior projection varying to less in well worn teeth (see series no. 23244, folder 2, fig. 3). In the premolars it is deeply bilobed, being sharply concave in the inner border; in the posterior portion of the series the protocone progressively lengthens, and becomes markedly narrower and flatter. The postprotoconal valley is broad in the premolars, and narrows slightly through the series. The development of the fold at the anterior end of the postprotoconal valley varies somewhat throughout the series, being considerable in certain premolars and in some molars. The fossettes are long and have a narrow appearance, owing to the deep incision of the opposed anterior and posterior walls. The inner walls are considerably complicated by



Figs. 19 to 22*c*. *Equus bautistensis*, n. sp. Lower dentition, occlusal views, × 1. Fig. 19, $P_{\overline{2}}$ to $M_{\overline{2}}$, no. 23196 (see fig. 23 for lateral view); figs. 20*a* to 20*c*, lower cheek teeth, nos. 23241, 23248, 23252; fig. 21, $P_{\overline{3}}$ to $M_{\overline{3}}$, no. 23913 (see fig. 24 for lateral view); fig. 22*a*, nos. 23250, 23241A, 23249. Bautista beds, California.



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Figs. 23 and 24. *Equus bautistensis*, n. sp. Fragment of mandible and lower teeth, lateral view, × ½. Fig. 23, $P_{\overline{2}}$ to $M_{\overline{2}}$, no. 23196; fig. 24, mandible with $P_{\overline{3}}$ to $M_{\overline{3}}$, no. 23913. Bautista beds, California.

accessory plications, especially those of little to moderately worn teeth. The *incisors* are large and still deeply cupped (fig. 25); the strongly concave outer edge of each incisor overlaps the convex inner edge of the adjoining tooth.

The *lower dentition* (figs. 19–24) is of a long and rather narrow-crowned type. The fold of the metaconid-metastylid column is broad, deep, and symmetrically V-shaped, becoming more open and asymmetrical in worn specimens through the simultaneous elongation of

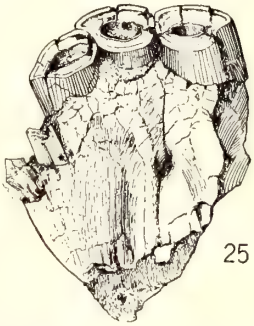
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Fig. 25. *Equus bautistensis*, n. sp. Premaxillary with incisor teeth, no. 23348, × ½. Bautista beds, California.

the metaconid. The inward folding between the protoconid and hypoconid is sharp, and deepens from the premolars to $M_{\overline{2}}$. In a worn series (fig. 19) the fold is slightly broader and rounder. In the molars the fold only meets the mouth of the metaconid-metastylid column (*versus* its much greater depth and breadth in old specimens of *E. caballus*). The inner wall of the hypoconid of $P_{\overline{4}}$ is considerably crinkled, as in *E. caballus*. The outer faces of the protoconid and hypoconid are markedly flattened, especially in the premolars, perhaps even more so than in *E. caballus*. The anterior portion of the entoconid resembles that of *E. caballus*, and the inward extent of the parastylid is similar.

The *mandible* is very broad (fig. 24), measuring 101.6 mm. in depth in the region of $P^{\underline{4}}$. The inferior border is not concave as in *E. caballus*, nor does it show the deep concavity anterior to the angle of the jaw seen in *E. occidentalis* of Rancho La Brea. It resembles more closely the mandible of *E. scotti*.[12]

The *premaxillary* is expanded in the region of the incisors, and appears to be of rather elongated proportions, pointing to a proportionately long-snouted form.

[12] Gidley, J. W. Bull. Am. Mus. Nat. Hist., vol. 13, p. 114, fig. 3, 1900.

MEASUREMENTS OF UPPER CHEEK TEETH OF EQUUS BAUTISTENSIS

	No. 23244, etc.	No. 23239, etc., type, premolars	No. 23236, etc.
P^2, anteroposterior diameter		(40.4) mm.	
P^2, transverse diameter		28.4	28.2 mm.
P^2, anteroposterior diameter of protocone		9.6	(9.9)
P^3, anteroposterior diameter		34.4	
P^3, transverse diameter		31.5	
P^3, anteroposterior diameter of protocone	10.9 mm.	(14.3)	
P^4, anteroposterior diameter	31.4	30.2	30.2
P^4, transverse diameter	28.5	29.5	28.5
P^4, anteroposterior diameter of protocone	12.3	13.4	13.3
M^1, anteroposterior diameter	27.9	27.8	27.4
M^1, transverse diameter	28.1	28.8	26.1
M^1, anteroposterior diameter of protocone	11.6	12	11.7
M^2, anteroposterior diameter		27.4	27.1
M^2, transverse diameter		27.6	25.7
M^2, anteroposterior diameter of protocone		11.3	11
M^3, anteroposterior diameter	32.9		31.7
M^3, transverse diameter	24.9	24	23.4
M^3, anteroposterior diameter of protocone	12.5		12.8

MEASUREMENTS OF LOWER CHEEK TEETH AND MANDIBLE OF EQUUS BAUTISTENSIS, REFERRED SPECIMENS

	Nos. 23249, 23241, 23250, 23248	No. 23196 mandible	No. 23913 mandible
P_2, anteroposterior diameter	33.6 mm.	36.2 mm.	
P_2, transverse diameter	14.6	14.2	
P_2, anteroposterior diameter of metaconid-metastylid column	15.2	15.6	
P_3, anteroposterior diameter	32.9	31.9	32.7 mm.
P_3, transverse diameter	(15.4)	14.2	18.8
P_3 anteroposterior diameter of metaconid-metastylid column	17.3	18.6	19.7
P_4, anteroposterior diameter	30.1	30.7	31.7
P_4, transverse diameter	16.3	13.4	17.5
P_4, anteroposterior diameter of metaconid-metastylid column	18.7	15.2	
M_1, anteroposterior diameter	31.1	27.5	27.3
M_1, transverse diameter	16.3		
M_1, anteroposterior diameter of metaconid-metastylid column	15.1	15.3	

Measurements of Lower Cheek Teeth and Mandible of Equus bautistensis, Referred Specimens—(*Continued*)

	No. 23196 mandible	No. 23913 mandible
$M_{\overline{2}}$, anteroposterior diameter	28.2 mm.	29.7 mm.
$M_{\overline{2}}$, transverse diameter	12.9	14.4
$M_{\overline{2}}$, anteroposterior diameter of metaconid-metastylid column	14	14.7
$M_{\overline{3}}$, anteroposterior diameter		34.4
$M_{\overline{3}}$, transverse diameter		13.7
$M_{\overline{3}}$, anteroposterior diameter of metaconid-metastylid column		13.1

Limb elements.—The unciform facet of the metacarpus (pl. 45, fig. 1) is largely developed. Specimen no. 23460 is fully as large as the metacarpus referred to *Equus pacificus* (Univ. Calif. Coll. Vert. Pal. 2410), and is considerably shorter than that of a new form from Idaho (Univ. Calif. Coll. Vert. Pal. 3836*c*). In comparison with the fore cannon bone an unassociated hind cannon bone, specimen no. 23459 (pl. 45, fig. 3*a*), is unusually light and long (measuring 285 mm. *versus* 242 mm. in the former), it is more slender and slightly shorter than that of *E. pacificus*. This more than proportionate lightness of the posterior element is indicated by further fragmentary remains. The cuboid facet of the metatarsus is large, but is not so square in shape as in the modern draught horse. The cuboid facet of the calcaneum is also less developed posteriorly than in the latter (pl. 45, fig. 3*c*).

Measurements of Hind Limb Elements of Equus bautistensis

Metacarpal III, no. 23460, greatest length	242 mm.
Metacarpal III, no. 23460, transverse width of distal trochlea	54
Metatarsal III, no. 23459, greatest length	285
Metatarsal III, no. 23459, transverse width of distal trochlea	53
Phalanx I, no. 23459, greatest length	92
Phalanx I, no. 23459, greatest length	95
Phalanx II, no. 23459, greatest length	57
Phalanx II, no. 23459, greatest length	59

Comparisons.—Compared with the figured dentition of *Equus scotti* Gidley that of *Equus bautistensis* may be of a slightly more primitive type, in that: (1) the upper cheek teeth are narrower transversely, the molars are slightly shorter anteroposteriorly, and their mesostyles

are slightly lighter; (2) the protocones are shorter anteroposteriorly, and considerably less extended both fore and aft; (3) the borders of the cement lakes are less plicated; (4) in the lower teeth the metaconid-metastylid column has less anteroposterior extension, and its inner groove is deep angular instead of shallow and flattened; and (5) the outer faces of the protoconid are perhaps less flattened.

Compared with *Equus occidentalis* Leidy, as seen in the Rancho La Brea type, the premolars may be slightly heavier, though the cheek teeth in general are of similar size. The new form generally differs as follows: (1) the protocones average longer in fore-and-after diameter, especially in the premolars, where their anterior production is most marked; in the molar portion of the series the anterior corner of the protocone is narrowed to pointed, instead of more oval in shape as in *E. occidentalis;* the inferior border of the protocone tends to be more deeply indented in the premolars, the postprotoconal valley is broader, and the accessory fold more marked than in the Rancho La Brea specimen; (2) the fossettes are broader and longer, and their borders are plicated, in contrast to the simple margins of *E. occidentalis;* (3) the lower cheek teeth average slightly narrower, and the fold of the metaconid-metastylid column averages somewhat deeper; (4) the outer faces of the protoconid and hypoconid are flatter than the more rounded faces of *E. occidentalis.*

Compared with *Pliohippus proversus* Merriam[13] the weight of evidence indicates the more advanced stage represented by *Equus bautistensis:* (1) $P^{\underline{3}}$ of the type specimen is but slightly larger than that of the *P. proversus* type specimen, its parastyle and mesostyle are but slightly lighter, and the styles of the teeth of both forms referred to the first molars are equal; (2) the protocone of the $P^{\underline{3}}$ has the greater anterior projection in the Bautista tooth, but the protocone of the $M^{\underline{1}}$ is as long anteroposteriorly in the *Pliohippus proversus* type; (3) the borders of the cement lakes are more complex and somewhat narrower in the Bautista form, though one specimen of *P. proversus* (no. 22328) shows a very considerable incision of the anterior lake margin; (4) in the lower teeth $P_{\overline{3}}$ of the *E. bautistensis* appears of about equal size with that of the portion of the single large tooth (no. 21332) referred to *P. proversus;* the groove of the metaconid-metastylid column of the Bautista form is markedly deeper and

[13] Merriam, John C. Relationship of Equus to Pliohippus suggested by Characters of a New Species from the Pliocene of California. Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 525–534, 1916.

sharper than in the *P. proversus* tooth, while the anteroposterior length of the column is about the same.

Compared with *Equus idahoensis* Merriam[14] (type and referred specimens, consisting of a worn P^3 and M^1 from the Payette and Snake rivers, Idaho), *E. bautistensis* grinders are fully as specialized. The upper teeth are of nearly equal size; the transverse thickness of the protocone of P^3 of *E. bautistensis* with its deeply indented inferior border somewhat suggests the premolar of *E. idahoensis.* Points of difference are: (1) the anterior projection of the protocone in P^3 of *E. bautistensis* (of series no. 23244) is more pronounced than in the *E. idahoensis* P^3 of the same stage of wear; (2) the large complicated lakes show no similarity to the narrow, simple, bordered fossettes of the worn Idaho P^3, but, on the other hand, somewhat resemble those of the less worn Idaho M^1, which, in turn, are relatively narrower and more complicated than those of the Rancho La Brea form; and (3) the post-protoconal valleys average broader throughout in the *E. bautistensis teeth.*

A wide range of characters is shown in *Equus stenonis*[15] as figured by Dr. C. J. Forsyth Major. The Bautista specimens, however, are: (1) considerably larger than any illustrated under *E. stenonis;* (2) their protocones, while somewhat resembling those shown in figure 1 of Dr. Major's plate, are shorter and much less produced anteriorly than those in his other figures; and (3) their lake borders are less complex than those of the illustrated teeth (excepting in the case of a worn series, figure 2 of the same plate, where the lakes of *E. stenonis,* as might be expected, are less plicated than in the moderately worn teeth of *E. bautistensis*).

Equus sivalensis[16] as figured by Dr. Lydekker suggests a stage of development similar to that of *E. bautistensis* in both the size of the teeth and the amount of folding of the fossette borders, as well as in the degree of anteroposterior elongation of the protocone. The length of the protocone shown in *E. namadicus,* on the contrary, would indicate a considerably more advanced stage.

Summary.—The dentition referred to *Equus bautistensis* in the summation of its character may be said to be of an advanced early

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[14] Merriam, John C. New Mammalia from the Idaho Formation. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 523–530, 1918.

[15] Major, C. J. Forsyth. Beiträge zur Geschichte der fossilen Pferde inbesonders Italiens. Abh. schweiz. palae. Ges., vol. 4, pt. 1, 1877.

[16] Lydekker, R. Palaeontologia Indica, ser. 10, vol. 2, pt. 3, pls. 14, 15, 1882; Record Geol. Surv. India, vol. 43, pt. 4, 1913.

Equus type. It may represent a later stage in equine development than does *Equus occidentalis* of Rancho La Brea. A considerable advance is indicated over the more specialized of such late *Pliohippus* forms as *P. proversus* Merriam of the Upper Etchegoin and *P. simplicidens* (Cope) of the Blanco. The dentition is considerably more primitive in character than that of *Equus namadicus* of the Indian and *E. complicatus* and *E. fraternus* of the American Pleistocene. The teeth apparently approach the stage represented by *E. niobarensis* of Nebraska and perhaps by *E. scotti* of Texas, and the Asiatic *E. sivalensis.*

TAPIRUS

Tapir remains have been met with but twice on the Pacific Coast, the known material consisting of a single lower molar from the Auriferous Gravels of California, referred to *Tapirus haysii californicus* Merriam,[17] and three associated upper molars from Cape Blanco, Oregon. Therefore one of the most interesting items in the present collection is the fragment of a lower jaw containing two tapiroid teeth excavated by the writer in the black clays of Bautista.

TAPIRUS MERRIAMI, n. sp.

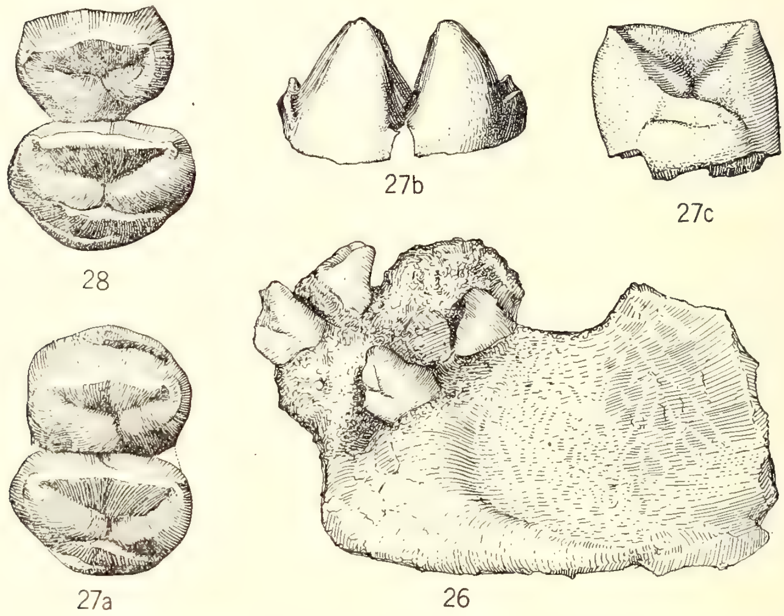
Type.—Two lower cheek teeth, contained in a section from the right side of a jaw, Univ. Calif. Coll. Vert. Pal. no. 23519 (figs. 26–28), Univ. Calif. loc. 3243. The anterior main crests of both teeth were found separated from the posterior crests, as shown in figure 26.

Characters.—The considerable difference in the transverse diameters of the two main crests as seen in both teeth of this specimen; the slightly greater size of the specimen as compared with the large *Tapirus haysii* Leidy from the Port Kennedy Cave, and the much greater size as compared with the small *Tapirus haysii californicus* Merriam from the Auriferous Gravels.

Description.—The two teeth are of similar pattern, and are of the characteristic form of molar teeth of this genus. The usual strong transverse ridges connecting the anterior and the posterior pairs of

[17] Merriam, J. C. Tapir Remains from late Cenozoic Beds of the Pacific Coast Region. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 169–175, 1913.

cusps in each tooth are well notched. The anterior of the two crests is much broader transversely and a trifle higher than the posterior. A comparison of the two teeth shows the forward crests of both to be of about equal size, but the higher crest of the second to be slightly less developed than that of the first tooth. The triturating edges of the first tooth are slightly worn, those of the second show no sign of



Figs. 26 to 28. *Tapirus merriami*, n. sp. Portion of mandible with lower teeth, no. 23519. Fig. 26, fragment of mandible with teeth in position as found, × ½. Figs. 27*a*, 27*b*, and 27*c*, $M_{\overline{1}}$, occlusal, outer and anterior views respectively; fig. 28, $M_{\overline{2}}$, occlusal view, natural size. Bautista beds, California.

wear, and the enamel of the whole is correspondingly dull and rugose instead of bright and polished as it is in the first tooth. The second tooth evidently occupied a position posterior to the first, and had not yet come into function. The first tooth is believed to represent M^1, the second M^2. The anterior extremity of each specimen is crossed by a typically low, inward-plunging ridge rising from the lower portions of the two anterior cones (the protoconid and metaconid). Tapiroid cingula occur at the exterior corner of these low ridges and at the posterior base of the second of the main transverse crests. In M^2 the low ridge is apparently more confluent with the wing of the protoconid, and the adjacent cingulum better developed than in M^1.

Through the separation of the teeth along their main transverse valleys and the resultant crumbling of the broken edges no positive evidence remains of the presence or absence of accessory tubercles. These usually occur in the teeth of the tapir at the inner and outer margins of the transverse valley, and a slight protuberance of the broken enamel at the exterior corner of the valley of the first tooth may here represent the remnant of such a tubercle.

Measurements

	Tapirus merriami no. 23519	Tapirus haysii californicus	Tapirus haysii Port Kennedy Cave	Tapirus haysii Kentucky	Tapirus terrestris	Protapirus robustus
$M_{\bar{1}}$, transverse diameter of anterior crest	23.7 mm.		21 mm.		17 mm.	15.5 mm.
$M_{\bar{1}}$, transverse diameter of posterior crest	22					
$M_{\bar{1}}$, greatest anteroposterior diameter	(32.5)		29		21.5	21
$M_{\bar{2}}$, transverse diameter of anterior crest	23.6	17.8	22	22.3	18	17.5
$M_{\bar{2}}$, transverse diameter of posterior crest	20.5	17.5				
$M_{\bar{2}}$, greatest anteroposterior diameter	(32.5)	25.3	31	27	22.5	26
Transverse width of posterior crest, per cent of anterior	.085	.091				

Comparisons.—The general structure of the teeth in specimen 23519 is markedly similar to that of the corresponding lower teeth of *Protapirus robustus*[18] of the John Day. They differ from the John Day teeth in their greater size, proportionate depression of crown, and the marked difference in the transverse widths of the anterior and posterior ridges of the individual teeth.

The specimens, so far as comparable, differ from *T. haysii californicus* in their much greater size; in the considerably greater relative difference existing between the transverse diameter of the anterior and the posterior main crests; in the lesser development of the anterior cingulum; and the greater notching of the crests. Specimen 23519 agrees with *T. haysii californicus* in the relative proportions of greatest transverse tooth width to anteroposterior tooth length.

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[18] Sinclair, Wm. J. Jour. Geol., vol. 9, 1901. Also type specimen of lower jaw in the Univ. Calif. Coll. Vert. Pal.

The measurements of the new teeth are somewhat greater than those of the large specimens of *Tapiris haysii* described by Dr. Leidy from Kentucky and by Cope from the Port Kennedy Cave.

Summary.—In taking into consideration the geographic occurrence of the specimen and the very slight degree of alteration in the teeth of the tapir from Oligocene to Pleistocene time, the writer believes that the difference in form between the present specimen and the only previously known lower tooth from California, as well as the considerable increase in size of the teeth over the described fossil forms, warrants the placing of the specimen in a separate species. He takes pleasure in naming the same in honor of Professor John C. Merriam.

TERTIARY DEPOSITS OF THE SAN TIMOTEO BADLANDS

The extensive deposits of the San Timoteo region stretch northwestward from the foothills of San Jacinto some eighteen miles, occupying the divide between the San Jacinto-Moreno and San Bernardino valleys, and underlying both to an unknown depth. They consist of a great mantle of coarse and fine materials, which were spread out from near-by highlands through long undulating cycles of slow gradation and rejuvenation, and were then folded and elevated. During the deposition one great portion at least of the underlying floor sank many hundred feet below the level of the sea. The plateaus and ridges of today are but dissected remnants of the original deposit. In their northern extent the deposits occur as benches about Beaumont at the head of the San Gorgonio Pass, where, spanning the gap between the San Bernardino and San Jacinto ranges, they rest on either side against granite foothills and coarse detrital mountain slopes. In their main extent they form the mesas of Yucaipe and Redlands and the badland ridges to the south of San Timoteo Cañon, a great north-and-south dipping region that plunges in hills and mesas westward from the pass into the San Bernardino Valley, and there disappears beneath the wash of the Santa Ana River (see fig. 1*c*, pl. 43, figs. 2 and 3, pl. 44, figs. 3 and 4).

Dr. Walter C. Mendenhall[19] in speaking of the uplifting of the San Bernardino Mountains along the line of the great San Andreas

[19] The Hydrology of San Bernardino Valley, California. U. S. Geol. Surv., Water-Supply and Irrigation Paper no. 142, Underground Water Ser. O, no. 45, 1905, pp. 30ff.

fault that runs northwest and southeast through Cajon and San Gorgonio passes, touches interestingly on the geological history of the region. His statement is in the main as follows:

. . . A . . . crustal movement whose beginnings may [at least] have been contemporaneous with . . . [the uplifting of the San Bernardinos] resulted . . . in the formation of an irregular arched wrinkle extending from San Jacinto Mountains northwest along the line of the Badlands, which separate San Timoteo Cañon from San Jacinto valley. . . . This fold can be traced on the surface as the Bunker Hill Dyke to a point nearly two miles somewhat south of west of San Bernardino. It probably extends even farther . . . as an underground feature . . . . This clay and gravel ridge has been one of the most effectual of subsurface dams. . . .

Before the San Bernardino Mountains were uplifted subaërial erosion had reduced an earlier topography to a condition in which the valleys were wide and generally level and the mountains low, although [on account of the granite rocks] often steep. Fragments of this old landscape are, it is believed, still preserved in practically the condition in which they existed previous to the deformation in . . . some of the higher parts of the San Bernardino Mountains. . . . The topography of these higher areas where it has not been altered by modern gorge producing agencies . . . is much like the region north of Elsinore [the Perris peneplain] . . . and it is believed that these two regions once formed a continuous surface. . . . It seems fair to assume about three thousand feet as the maximum relief on the [this] old surface . . . now only 2000 or 2500 feet below San Bernardino. . . . Perhaps bed-rock hills exist there . . . or the bed rock floor of the middle valley may be relatively smooth like that of the Perris Valley . . . . The rocks of the upper San Bernardino region may be subdivided into two general classes . . . those which outcrop everywhere in the higher regions . . . [schists, gneisses, diorites, marbles, quartz-porphyries, sandstones, and conglomerates] and the clays and alluvium . . . [sands, gravels, and clays] which fill the valleys, underlie most of the fertile mesas and form the greater part of the Badlands between San Jacinto and upper Santa Ana valleys. But at their base [that is, of the Badlands] is a rather wide-spread series of fine clays and shales . . . [and] from the fineness of these . . . and the fact that they are bent into sharp folds we know that extensive earth movements have taken place since their deposition, . . . that the clays are older than the formation of the San Bernardino valley and . . . mountains. . . . They were likely deposited in a lake like Bear Lake, but much longer, and larger on the old land surface of rather moderate relief . . . [which] probably occupied the lowest of the valleys at that time; and within it islands of the granitic or gneissoid bedrock rose perhaps as the Box Springs and Lake View mountains now rise above the Perris and San Jacinto plains. . . .

Sometime after the deposition of the Badlands clays a crustal movement began, which folded the clay and seems to have elevated the San Bernardinos . . . until they stood above the adjacent valleys but were perhaps 2500 feet lower than at present. It is probable that at the same time San Bernardino Valley subsided somewhat, so that its rock floor, sheeted over by lacustrine silts, stood at a lower elevation than before the movement. . . . Mountain streams cut deep cañons and carried the products of their erosional activity out into the lowlands as they do now. This detritus . . . was probably not quite so coarse as the fan material of today. It was widely distributed over the lowlands south of the mountains, boulder beds, sand beds, and clays alternating in an uncertain succession until many hundreds of feet of alluvium were piled up.

At the close of this epoch . . . movement was resumed along the lines followed during the earlier period . . . [lifting] the San Bernardino Mountains to their present elevation . . . [and] the earlier deposited alluvial wash into the sloping mesas of Smiley Heights and Redlands Heights . . . the Yucipe bench to a position somewhat higher than it had occupied before, and the coarse boulder beds south of San Timoteo Cañon [the Badlands] were given the strong northern dip which they now have . . . [while] San Bernardino Valley seems to have again subsided. After this readjustment . . . erosion became more active than ever, the present deep cañons were cut, the modern fans were built, and the great [later] alluvial filling which makes the present surface of the San Bernardino Valley and serves as such a valuable storage reservoir . . . accumulated.

The "working hypothesis"[20] of Dr. Mendenhall while in the field, based on induration and physical character, held the cobble beds at the top of the Badlands alluvium as late Pliocene or early Pleistocene, and the finer beds at the bottom as probably Pliocene and perhaps late Pliocene in age. He states that the only fossils collected were a few shells, secured in a shaft in a carbonaceous streak in the gritty clays of the area, which Dr. Dall reported as belonging to brackish or fresh water types that might represent any period from the Miocene to the present.

The cañon of the San Timoteo divides this long sedimentary area diagonally from southeast to northwest into two natural topographical subdivisions, a low-rimmed northern and a higher-rimmed southern portion. The present investigation was confined to the latter portion. Its desolate waste forms the so-called Badlands, which stretch east and west in striking contrast to the watered mesas of Yucaipe and Redlands that lie beyond the northern wall. Long benches at the mouth of the San Timoteo Cañon point to the antecedent nature of the lower portions of its stream and to the unity of deposition, as well as to the slowness of the general uplift. The stream in its higher reaches is joined by two washes, that drain the upper area of the main plateau and unite with a third from the more northern portion of the same. Broad, deep levels, which former meanderings of the three streams have cut into the Beaumont floor, line the troughs of the present constricted washes. It is interesting to note that while the cañon of the San Timoteo on the north side of the Badlands has worn its way westward in the direction of the normal drainage of the San Bernardino basin, the slope of the Moreno Valley, which cuts and limits the Badlands on the south, is to the east.

[20] Personal communication by Dr. Mendenhall.

The structural axis of the San Timoteo fold lies within the southern area and considerably to the south of the present crest. The trend of the strike is to the east and west of the compass. The respective limbs of the major fold pass to unknown depth beneath the recent alluvium of the north and south valleys. The occurrence at the edge of the Badlands in the Moreno Valley of strata which have a rather constant dip of 35 degrees southwest, together with the marked evidence of great faulting along the same line a short distance to the east in the Claremont region, strongly suggest the presence of a break along the valley line. Borings in the valley have never revealed the distance to bedrock, this on the San Bernardino side lies a thousand or two thousand feet below sea level and thus affords strong proof of the one-time subsidence of the region.

South of Beaumont, where monadnock-like bosses protrude through the sedimentary crust, as in the Crafton Hills, and again in Reche Cañon, coarse San Timoteo beds are seen in direct contact with the old eroded basement surface. In their southeastern extent, these same upper San Timoteo beds are found unconformably overlying an earlier more indurated and, generally speaking, finer series of sediments, the lower San Timoteo or Eden beds. The Eden series, in the same manner as the upper deposit, is found in places in direct contact with the basement metamorphics. To the southeast, in the Potrero Basin, it occurs overlying beds of coarse arkosic, which there intervene between it and the complex of older rocks exposed in the foothills of the San Jacinto Range.

UPPER SAN TIMOTEO DEPOSITION

There is a material difference between the north and south flanks of the long Badlands ridge of the San Timoteo. The northern exposure rises by gentle-dip slopes, thickly brush grown, to near-by crests; only here and there do the bluffs appearing at the sides of its short valleys afford an occasional view of north-dipping bedding planes. The southern flanks, on the other hand, first plunging abruptly downward by steep contra-dip faces, and then falling away to the distant valley by a long broken series of twisting knife-edged ridges, afford fine exposures of somewhat broken but generally south-dipping strata in many an east- and west-facing bluff. Here the usual dearth of south side vegetation has assisted the process of erosion.

Two roads connect San Jacinto Valley and San Timoteo Cañons, crossing the formation in the general direction of the dip. The western road, Moreno Grade, allows but a poor opportunity for the study of the structure, its main exposures occurring in massive deposits of compact, gray-brown sandstone, which passes southwestwardly into an equally massive gray-white area. The more eastern road by way of the new Rabbit Cut (San Gorgonio Drive) fortunately affords splendid exposures for the examination of the strata and for the study of the marvelous series of folds and faults which have taken place in this particular region (pl. 44, fig. 3).

The lower hills on the San Jacinto-Moreno Valley-side are formed of a series of fine and coarser sandstone interstratified with layers of clay. North across the strike the latter are followed by the sharp south-dipping beds of the central area, remarkable for their broad layers of heavily cemented fanglomerate, which, more resistant to erosion than the interbedded gray-brown and yellow clay sands and sandstones, project in bold weathered bands. Still more to the north the sharply south-dipping beds of the mid-elevation are followed first by a more gently dipping series and then by a broken indeterminate area that apparently represents the axis of the anticline. The present crest of the ridge lies 500 feet higher, and in the mid-extent of the Badlands a quarter of a mile to the northwest of the axial line. The upper and more recent beds of the north-dipping layers of the crest are more brightly colored and sandy than the older beds lying immediately below both to the north and south, tending to pink-reddish instead of yellowish tones. They lack, too, the great gray interstratified bands of cemented angular rock fragments so prominent in the lower southern area.

The San Timoteo deposit as a whole is strongly characterized by the coarse sand and cobble beds which appear running through the yellowish and pinkish browns of the bluffs, as well as by fragments of the same which form a characteristic litter throughout much of the top soil. The constituent cobbles of the coarser layers while considerably worn on the edges are hardly as uniformly rounded as the average resultant of stream deposition. Their angularity as well as the prevalence of mica and occasional considerable amounts of gypsum, forbid the consideration of the deposit as of purely alluvial formation. The evidence points rather to its origin as the great slope-wash of a semiarid region, the formation for which Professor Lawson has proposed the term "fanglomerate."

Occurrence

As has been mentioned above, the beds lying beyond the two-thousand foot level of the north limb of the San Timoteo fold carry considerably less clay than those lying below. No determinative material has been secured from this sandy region of the crest and it is, therefore, impossible to ascertain whether it contains a more advanced fauna than that of the lower clay beds to which the collecting has been almost entirely confined. Fossil remains are uncommon but have been found both in these more or less gritty clay strata, ranging in color through browns, yellows, light blues and greens, and also in the underlying clayey sands and coarser fanglomeratic sands.

Upper San Timoteo Fossil Localities where More Important Specimens Were Collected

All localities in T. 3 S, R. 2 W, San Bernardino B. L. and M., Elsinore Quadrangle, U. S. Geol. Surv. Sheets (see fig. 1*c*).

Univ. Calif. loc.	
3248	NW cor. of SE ½ of Sec. 9; E end of third hogback from N of burnt over portion of main N and S ridge.
3249	SE ¼ of SE ¼ of Sec. 9; W of no. 1 camp across N and S ridge of hogback.
3250	SE ¼ of Sec. 14; below junction of first W dropping ridge E of Rabbit Grade, with the high main ridge extending S from Rabbit Grade to Eden Mountain.
3251	NW ¼ of Sec. 14; Appleby Ridge E of the ''Frenchman's.''
3252	Midline between SW and NW ¼ of Sec. 15; near lane in cañon leading to no. 1 camp.
3253	Central portion of SE ¼ of Sec. 9; E end of fourth hogback N of ''Burnt Hills,'' 150 yards N of location; no. 4, fig. 1*c*.
3254	N ½ of NE ¼ of Sec. 9; NE of location.
3255	NE portion of SE ¼ of Sec. 10; head of ridge leading NE from no. 1 camp; no. 5, fig. 1*c*.
3256	SE ¼ of SE ¼ of Sec. 5; the saddle in S end of first N and S ridge W of Oil Cañon; no. 2, fig. 1*c*.
	Same ridge as above just north of saddle.
3257	Camp no. 1 to ''Burnt Hills.''
3258	NW ¼ of SE ¼ of Sec. 6; low hills W side of the mouth of Armstrong's Canon; no. 1, fig. 1*c*.
3259	E mid-portion of SW ¼ of Sec. 9; low S end of ''Burnt Hill'' ridge, ¼ mile from main road.
3260	NE portion of NE ¼ of Sec. 22; low hills ¼ mile from main road and ¼ mile W of adobe house of no. 1 camp cañon; no. 6, fig. 1*c*.
3261	Above orange grove in low hills towards Moreno Grade.
3262	NW ¼ of SW ¼ of Sec. 4; E exposure of main ridge E of Oil Cañon; no. 3, fig. 1*c*.
3263	Nos. 567–571.
3264	No. 23275, Beaumont Road, SE corner of Sec. 11; no. 7, fig. 1*c*.

DESCRIPTION OF SAN TIMOTEO PLIOCENE FAUNA

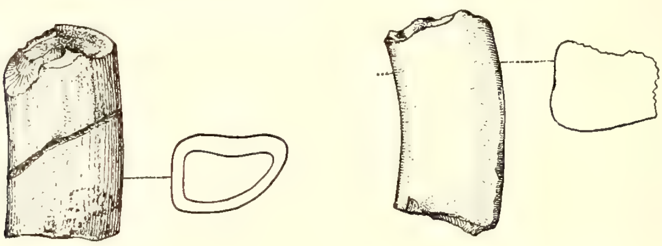
The exploration of the San Timoteo has determined the former existence of:

Megalonyx?, sp.	Pliohippus francescana, n. sp.
Pliauchenia?, sp.	Pliohippus francescana minor, n. subsp.
Camelid, small, sp.	Testudinate remains, two indet. sp.
Cervid(?), medium, n. sp.	

MEGALONYX?, sp.

Material.—Two cheek teeth, Univ. Calif. Coll. Vert. Pal. no. 23373 (fig. 29), Univ. Calif. loc. 3259.

The writer referred these teeth to Dr. Chester Stock, who has very kindly made the following report:



29a 29b

Figs. 29*a* and 29*b*. *Megalonyx?*, sp. Fig. 29*a*, last upper molar, no. 23373, anterior view; fig. 29*b*, fragment of tooth, × 1. San Timoteo beds, California.

In so far as the material allows of determination, the genus *Megalonyx* seems to be represented. Specimen 23373 (fig. 29*a*) is a fifth or last tooth of the left superior series. It agrees closely in size and shape with a corresponding tooth from the Pleistocene of Potter Creek Cave, which I have tentatively referred[21] to *Megalonyx*. The specimen, no. 23373, differs from the superior tooth of *M. jeffersoni* in its smaller size, as indicated by the following comparison of measurements:

	No. 23373	Megalonyx jeffersoni	Megalonyx wheatleyi
Transverse diameter	14.7 mm.	21 mm.	17 mm.
Anteroposterior diameter	*a*10	*a*14.8	10

a, approximate.

Contrasted with the fifth superior tooth in the maxillary of a ground sloth (Univ. Calif. Coll. Vert. Pal. 22779)[22] secured from the White Bluffs exposed on the Columbia River near Hanford, no. 23373 is seen to differ decidedly in shape.

[21] Stock, Chester. Recent Studies on the Skull and Dentition of *Nothrotherium* from Rancho La Brea. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 137–164, 1917.

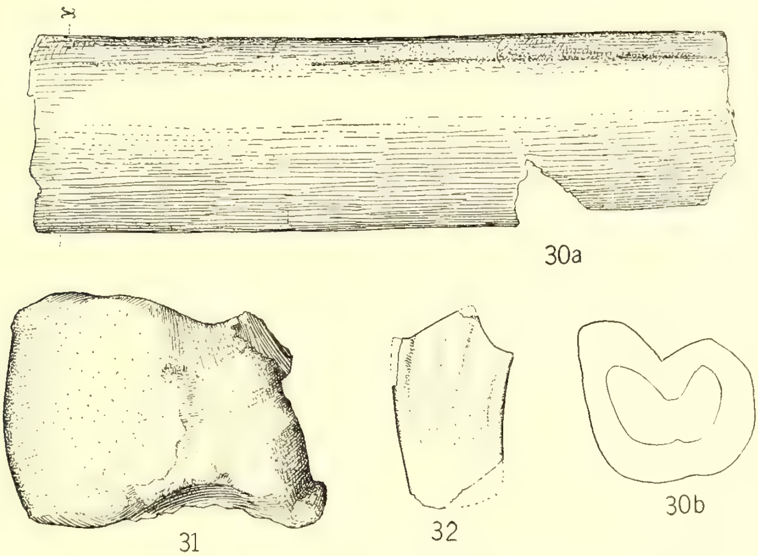
[22] Merriam, John C., and Buwalda, John P. Age of Strata Referred to the Ellensburg Formation in the White Bluffs of the Columbia River. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 255–266, pl. 13, 1917.

It approaches more the triangular form, being distinctly of less anteroposterior diameter on the outer side than the fifth tooth of the fragment from the White Bluffs. It is also of slightly less transverse width than the fifth tooth of the latter specimen. No. 23373 differs also from the fifth superior tooth of *Megalonyx leidyi* in smaller size and in shape. Compared to the corresponding tooth in *M. wheatleyi*,[23] the California specimen is seen to agree in anteroposterior diameter but differs slightly in transverse width (see measurements above). According to Cope the shape of this tooth in *M. wheatleyi* is triangular but may vary somewhat in different individuals.

The second specimen, no. 23373 (fig. 29*b*), is too fragmentary to allow definite determination.

PLIAUCHENIA?, sp.

Material.—The section of an artiodactyl metapodial, Univ. Calif. Coll. Vert. Pal. no. 23760 (fig. 30), from a locality northeast of loc. 3263.



Figs. 30*a* and 30*b*. *Pliauchenia?*, sp. Section of metapodial, no. 23760. × ½. Fig. 30*a*, lateral view; fig. 30*b*, cross section.

Fig. 31. Camelid? Scaphoid, no. 23397, × 1.

Fig. 32. Camelid? Part of cheek tooth, no. 23762, × 1. San Timoteo beds, California.

The specimen measures 51 mm. in mid-anteroposterior cross section. It is believed to represent a large camel of the *Pliauchenia* type, and with the fragmentary remains of the following section suggests the probable prevalence of the camel in the fauna of this horizon.

[23] Cope, Edward D. Vertebrate Remains from Port Kennedy Bone Deposit. Jour. Acad. Nat. Sci. Phila., (2), vol. 11, p. 213, 1899.

CAMELID?

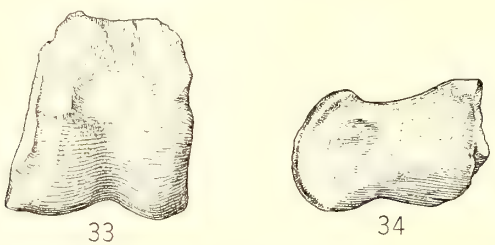
Material.—A scaphoid, Univ. Calif. Coll. Vert. Pal. no. 23397 (fig. 31), Univ. Calif. loc. 3249, and the outer shell of a molar, Univ. Calif. Coll. Vert. Pal. no. 23762 (fig. 32), Univ. Calif. loc. 3262; and the distal portion of a phalanx.

The small camelid scaphoid (fig. 31) in the relative proportions of the facets exhibits characters of *Procamelus* rather than of *Camelops,* interestingly resembling a lone scaphoid from the Merychippus zone of the Coalinga Miocene. The bone is considerably smaller than that of the medium sized camel of Bautista.

CERVID?

Material.—The distal half of an astragalus, Univ. Calif. Coll. Vert. Pal. 23763 (fig. 33), Univ. Calif. loc. 3262; and the distal portion of a phalanx (fig. 34), Univ. Calif. Coll. Vert. Pal. 23761, Univ. Calif. loc. 3251.

The specimens suggest the presence of a cervid of medium size. The outer condyle of the inferior trochlea of the astragalus is broad,

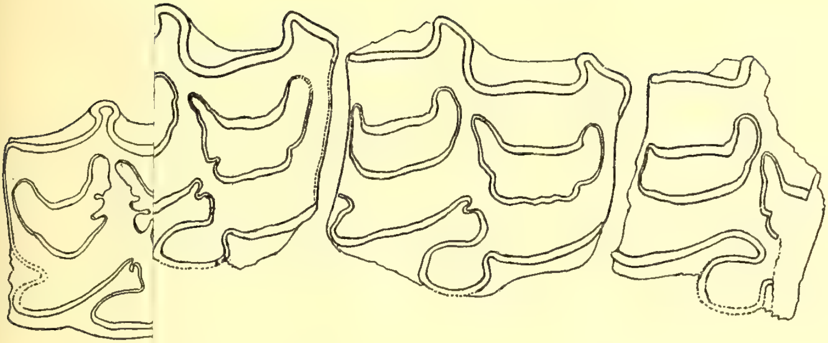


Figs. 33 and 34. Cervid? Fig. 33, distal portion of astragalus, no. 23763; fig. 34, phalanx, no. 23761; × 1. San Timoteo beds, California.

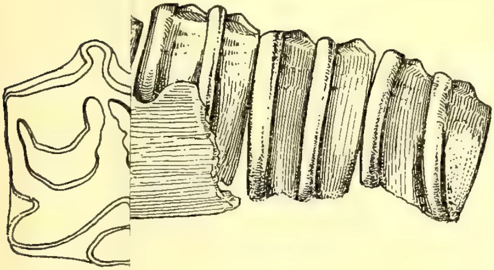
the adjacent groove is sharply defined, and the two condyles of the trochlea, as seen mid-dorsally, terminate at either end of the connecting ridge in knobs, as in the deer. The seeming non-deer-like shallowness of the groove of the distal end may be attributed to abrasion rather than to antelope affinities. The portion of a first phalanx (fig. 34) is also tentatively referred to the deer; its characters are broad, cervid-like, and not narrowed and elongated as in the antelope.

PLIOHIPPUS FRANCESCANA, n. sp.

Type.—A complete upper series of worn cheek teeth from right side of the jaw, series no. 23277 (folder 3, figs. 1*a*–1*b*), found associated with the three molars of the left side, nos. 23261, 23261A, 23262 (figs. 35*a*–35*b*), Univ. Calif. loc. 3253. To the type are referred three unworn upper teeth, nos. 23270, 23278,



2e



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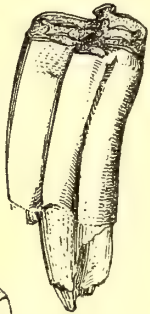
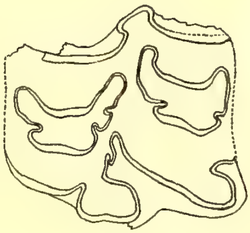
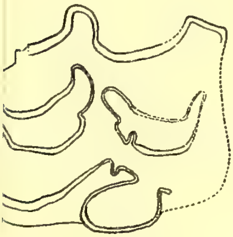


4b



4a



3e

San Timoteo beds, California.

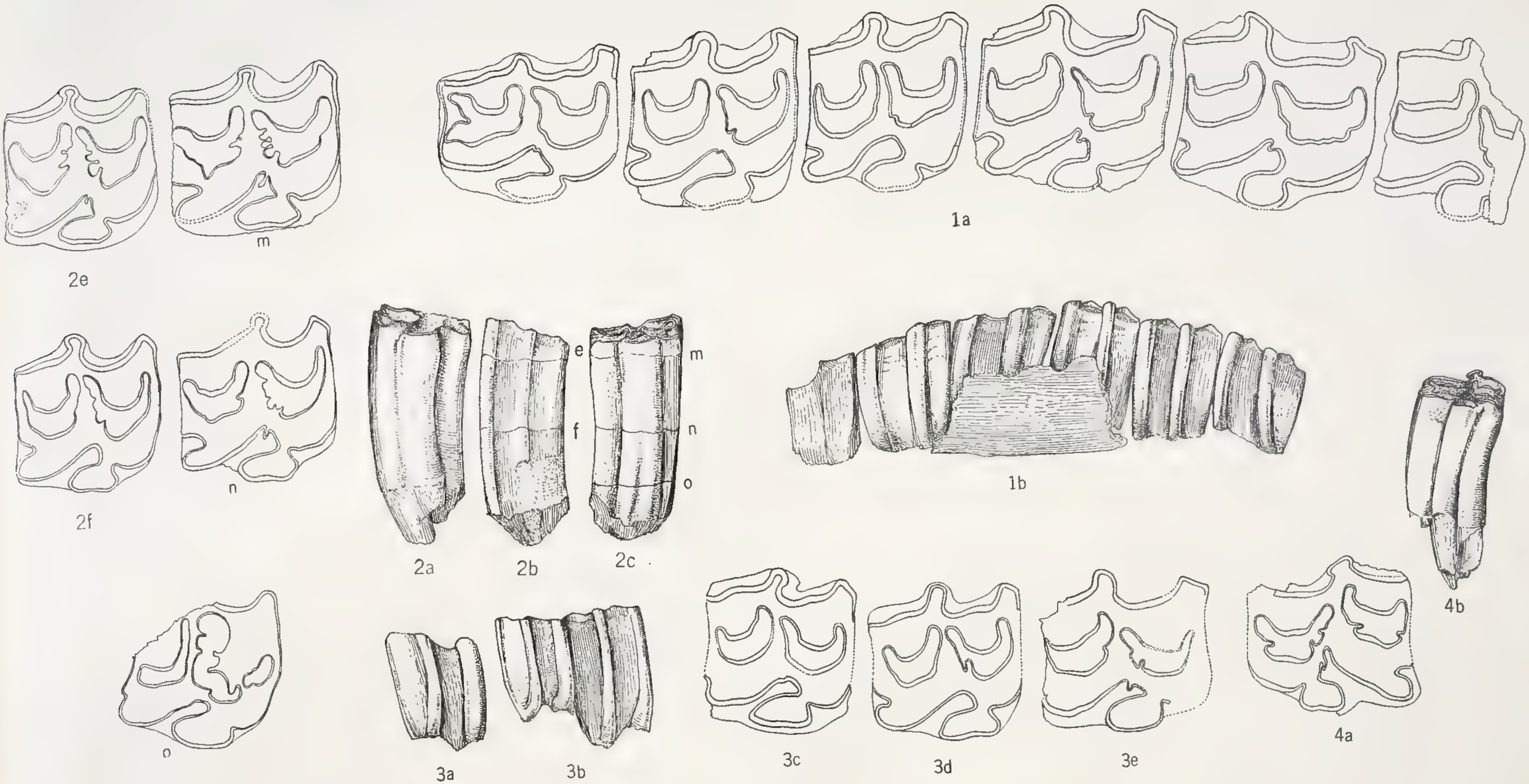
Fi w, × ½. (See text figs. 35*a*–35*b*.)

Fi *n, o,* cross sections of *c*; nos. 23270, 23278, 23268.

Fi espectively (see P^4 and M^1 of type specimen, figs. 39*a*–39*b*),
nos. 2326

Fi

Al



EXPLANATION OF FOLDER 3

Upper dentition of *Pliohippus francescana*, n. sp., figs. 1 and 2, and *P. francescana minor*, n. subsp. (figs. 3–4). San Timoteo beds, California.

Fig. 1. Associated worn series of type specimen of *Pliohippus francescana*, no. 23277; *a*, occlusal view, natural size; *b*, lateral view, × ½. (See text figs. 35*a*–35*b*.)

Fig. 2. Three little worn upper cheek teeth, referred to *P. francescana*, natural size; *a*, *b*, *c*, elevations; *e*, *f*, cross sections of *b*; *m*, *n*, *o*, cross sections of *c*; nos. 23270, 23278, 23268.

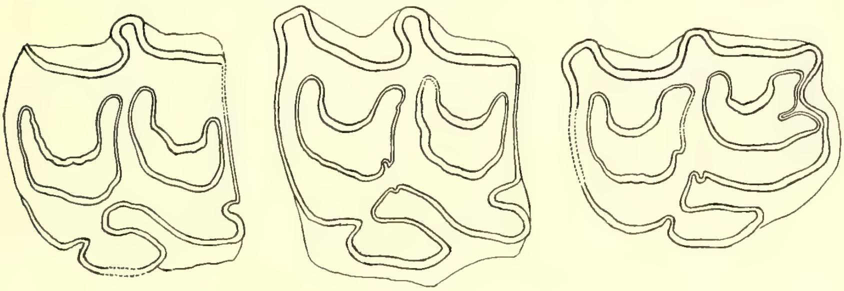
Fig. 3. *Pliohippus francescana minor*, type specimen; *a*, *b*, lateral views, × ½; *c*, *d*, *e*, occlusal views of M^1, P^4 (reversed), and P^2 respectively (see P^4 and M^1 of type specimen, figs. 39*a*–39*b*), nos. 23267, 23263, 23266, natural size.

Fig. 4. *P. francescana minor*, referred specimen, no. 23275; *a*, occlusal view, natural size; *b*, inner view, × ½. (See figs. 38*a*–38*b*.)

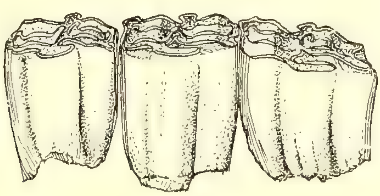
All Univ. Calif. Coll. Vert. Pal.

23268 (folder 3, fig. 2), Univ. Calif. loc. 3248; a worn left lower cheek series, complete except for $M_{\overline{3}}$, no. 23276 (figs. 36*a*–36*b*), Univ. Calif. loc. 3263; and two separate teeth, $P_{\overline{4}}$ and $M_{\overline{1}}$ of the right side, nos. 23271, 23272 (fig. 37), Univ. Calif. loc. 3262. Also certain limb elements (pl. 46) from various localities (listed on page 327). All specimens in Univ. Calif. Coll. Vert. Pal.

Characters.—Pliohippus francescana is characterized by: (1) the great size of the upper cheek tooth series with accompanying heaviness of the parastyle and mesostyle; (2) the nearly cylindrical cross section of the protocone of the $P^{\underline{3}}$ and $P^{\underline{4}}$ (the inner border being rounded and



35a



35b

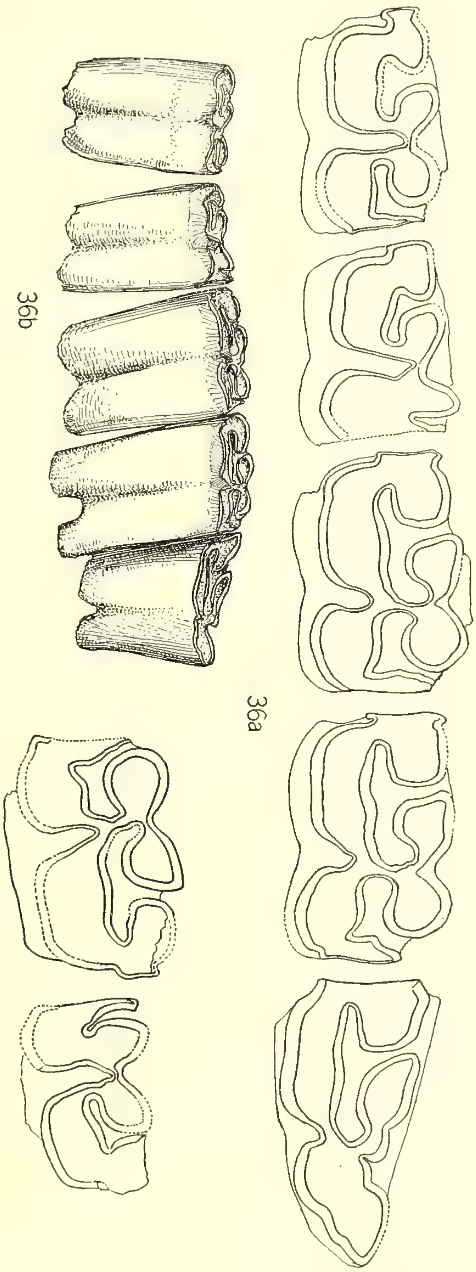
Figs. 35*a* and 35*b*. *Pliohippus francescana*, n. sp. Molars from left side of jaw found associated with series of type specimen (see folder 3, fig. 1), nos. 23261, 23261A, and 23262; *a*, occlusal view, × 1; *b*, lateral view, × ½. San Timoteo beds, California.

unindented, as seen in the worn series of the type specimen), and the markedly slight anterior projection of the elongated protocones of the molar portions of the series; (3) the simple outer margins of the large fossettes and convexity of the adjacent borders of the paracones and metacones; (4) the exceptional transverse thickness of the referred worn lower cheek series; (5) the great development of the fold between protoconid and hypoconid, and the depth and roundness of the external face of the protoconid.

Description.—The dentition (see folder 3, figs. 1 and 2; also text figs. 35*a* and 35*b*) represents a form of exceptional size, with heavy parastyle and mesostyle and strongly developed cementation. The teeth of the type specimen are much worn (being of the same stage

of wear as the worn Bautista series shown in folder 2, fig. 3). The protocone of P^2 and of P^3 in cross-section tends toward cylindrical form, the inner border being without trace of the usual premolar indentation, and the cusp strongly suggesting that of the more primitive *Pliohippus* forms of the lower horizon. In the molars the corresponding cusps are elongated and thick, with flattened inner borders. The lack of anterior projection of the protocone may be studied in the series of sections of two of three referred unworn teeth (folder 3, fig. 2). The degree of anterior projection of this cusp in equine teeth is somewhat proportional to the stage of wear, the amount of the same in the top section of a slightly worn molar being greater than that in the lower section, so that the absolute amount of projection of the protocone in the unworn section of the present form may exceed that of the worn tooth of a more advanced equine, i.e., *Equus bautistensis.* The postprotoconal valley is of moderate width, narrowest in P^2 and in the molars, and has the usual accessory fold, this being most prominent in the less worn teeth. It is absent in a worn M^1. The cement lakes in the premolars are long and broad, with short, broad horns; in the narrower molars they are more contracted and the horns considerably elongated, resulting in a great curvature of the adjoining borders of the paracone and metacone, and accompanied with an unusual angularity of the inner lake margins. The tip of the anterior prong of the postfossette in the premolars lies superior to that of the anterior fossette; the two horns in the first molar occupy nearly subequal positions. The margins of the more worn fossettes are extremely simple, that of the posterior lake being nearly without plications, and the anterior lake having but a small single fold in its anterior and posterior walls; in earlier stages the median wall of the anterior fossette is somewhat plicated.

The lower series and associated specimens referred to the type are considerably worn. The teeth are of a large and very thickly proportioned type. The wings of the metaconid-metastylid column are broad and rounded in the premolars, and narrowed in the molars. The groove of the metaconid-metastylid column is moderately deep, sharp, and symmetrical rather than asymmetrical (see the proportionately worn series from Bautista, fig. 19). The fold between the protoconid-hypoconid is remarkably wide and deep, and in the molar portion of the series is greatly produced within the expanded mouth of the metaconid-metastylid column. The presence of a prominent accessory infolding of the valley in less worn teeth is suggested by a



Figs. 36a to 37. *Pliohippus francescana*, n. sp. Lower dentition. Fig. 36a, $P_{\overline{2}}$ to $M_{\overline{2}}$, no. 23276, occlusal view, × 1; fig. 36b, same series, outer view, × ½; fig. 37, $P_{\overline{4}}$, no. 23271, $M_{\overline{1}}$, no. 23272, occlusal views, × 1. San Timoteo beds, California.

plication in the posterior wall. The outer face of the protoconid is deeply rounded, that of the hypoconid very slightly flattened. The entoconid is large and full in the premolars, considerably reduced and more oval in the molars.

A reduction of the first in respect to the second molar is noted in both the lower and upper cheek-teeth. The first molar, in the type specimen held in a fragment of the jaw with P^4, in anteroposterior diameter is the least of the series. M^2 of the type specimen has been somewhat cramped and deflected from the normal tooth line, to which it lies superior. In the reduction of M^1 instead of M^2 the form parallels the smaller *Pliohippus* forms of the underlying Eden beds (see complete series under Eden). The lower series is referred to the form represented by the upper teeth of the type specimen, being quite too heavy for the smaller horse from the same formation. The more than usual difference between the anteroposterior length of the third premolar to second molar portion of the row in the upper and in the lower series, i.e., 136 mm., versus 127 mm. (the sums of the separate anteroposterior diameters) may represent individual variation and difference in stage of wear.

Measurements of Dentition of Pliohippus francescana, n. sp.
Type, Univ. Calif. Coll. Vert. Pal. 23277

P^2, anteroposterior diameter	35 mm.
P^2, transverse diameter	28.4
P^2, length of protocone	12.5
P^3, anteroposterior diameter	35.6
P^3, transverse diameter	35.4
P^3, length of protocone	9
P^4, anteroposterior diameter	36.5
P^4, transverse diameter	34.8
P^4, length of protocone	10
M^1, anteroposterior diameter	(34)
M^1, transverse diameter	30
M^1, length of protocone	11
M^2, anteroposterior diameter	32.4
M^2, transverse diameter	31.3
M^2, length of protocone	13

Referred Specimen, Univ. Calif. Coll. Vert. Pal. 23276

P_2, anteroposterior diameter	38
P_2 transverse diameter	18
P_3, anteroposterior diameter	33
P_3, transverse diameter	19
P_3, length of metaconid-metastylid column	19.5

$P_{\overline{4}}$, anteroposterior diameter	31.5 mm.
$P_{\overline{4}}$, transverse diameter	20
$P_{\overline{4}}$, length of metaconid-metastylid column	18.8
$M_{\overline{1}}$, anteroposterior diameter	26
$M_{\overline{1}}$, transverse diameter	17
$M_{\overline{1}}$, length of metaconid-metastylid column	15.2
$M_{\overline{2}}$, anteroposterior diameter	28.8
$M_{\overline{2}}$, transverse diameter	16.5

Limb elements.—A metacarpal (pl. 46, fig. 1), with the first and second phalanges, no. 23521, loc. 3255. A metacarpal, no. 23474, loc. 3260 (pl. 46, fig. 3); proximal and distal portions of a metacarpal no. 23475, associated with proximal portions of a first and third phalanx, no. 23500, loc. 3254 (pl. 46 fig. 2); metatarsus no. 23476, loc. 3215 (pl. 46, fig. 4); proximal portions of first phalanges, nos. 24230, 24231 (pl. 46, fig. 5); the top of a calcaneum, no. 23764, loc. 3249 (pl. 46, fig. 6). All specimens in Univ. Calif. Coll. Vert. Pal.; all Eden localities.

A metacarpus with first and second phalanges was found in proximity to the four molars of *Pliohippus francescana minor,* but it is believed to be too large comparatively for reference to the small species, and together with the balance of the material, which is all of proportionate size, is tentatively placed under the larger form. A second metacarpus and portions of a third, associated with pieces of phalanges and pedal bone, agree specifically with the first. The unciform facet is well developed, the bones being those of a monodactyl horse in all particulars. Compared to the generally larger *E. bautistensis* (pl. 45), the metacarpus is slightly longer and lighter, as are the associated podial elements. The metatarsus is alone represented by the proximal end of a single specimen, and appears fully as heavy as the referred metacarpus. The cuboid facet is proportionately smaller than in *E. bautistensis.* The posterior elements are all somewhat lighter than those of *E. bautistensis.*

Comparisons.—In size the $P^{\underline{4}}$ of the series nearly equals that of the type specimen of *Equus giganteus,*[24] which, as figured by Gidley, strongly suggests a tooth of the $P^{\underline{4}}$ position. The long anterior projection of the elongate protocone and the complicated lake borders of *E. giganteus,* however, are unmistakably of the genus *Equus.* It is of great interest to find a *Pliohippus* dentition of as large size as that suggested by this large tooth of a later *Equus.*

The dentition referred to *Pliohippus francescana* differs from that of *Equus bautistensis* in: (1) its larger size and heavier styles; (2) the remarkable shortness as well as the circular section and unindented

[24] Gidley, J. W. Tooth Characters and Revisions of the North American Species of the Genus *Equus.* Bull. Am. Mus. Nat. Hist., vol. 14, p. 137, 1901.

lower edge of the protocone of the premolars; (3) the comparatively unplicated borders of the large and broad fossettes (the comparisons made between teeth of equal and various stages of wear); (4) the much greater transverse thickness of the lower dentition; (5) the relative shallowness of the groove of the metaconid-metastylid column; (6) the tremendous development of the fold between the protoconid and hypoconid, and the much greater convexity of the outer faces of both the protoconid and hypoconid. In short, the résumé of the characters of upper and lower teeth evidences the much greater primitiveness of *P. francescana* as compared to *E. bautistensis.*

The upper series of the new form is markedly heavier than the teeth representing the types of *Pliohippus proversus* Merriam and *P. simplicidens* Cope. The character of the protocone is more primitive than that seen in the *P. proversus* specimen. The *P. simplicidens* tooth characters are discussed in detail below in a comparison with *P. cumminsii* and the small San Timoteo horse.

Important differences between the worn lower series referred to the new form and those of the less worn series referred by Professor Cope to *P. simplicidens*[25] are: (1) the much greater transverse diameter; (2) the more rounded exterior faces of the protoconid and hypoconid; (3) the broader fold between protoconid and hypoconid, the production reaching the maximum within the metaconid-metastylid column of the first molar instead of the second molar as in *P. simplicidens;* (4) the narrower and more produced parastyle; and (5) the anteroposterior diameter of the first molar, which is the least of the series, perhaps partly a condition of age. By all characters, as understood, the new lower series represents a more primitive form than do the lower teeth referred by Cope to *P. simplicidens.*

Compared with certain small, *Pliohippus*-like lower molars referred to the type *P. proversus*[26] of the Upper Etchegoin the *P. francescana* lower teeth are seen to be considerably larger, the anteroposterior length of the metaconid-metastylid column to be greater, and the exterior groove shallower. The teeth, however, show a similar degree of primitiveness in the proportionate production of the fold between protoconid and hypoconid and the convexity of the exterior faces of the protoconid.

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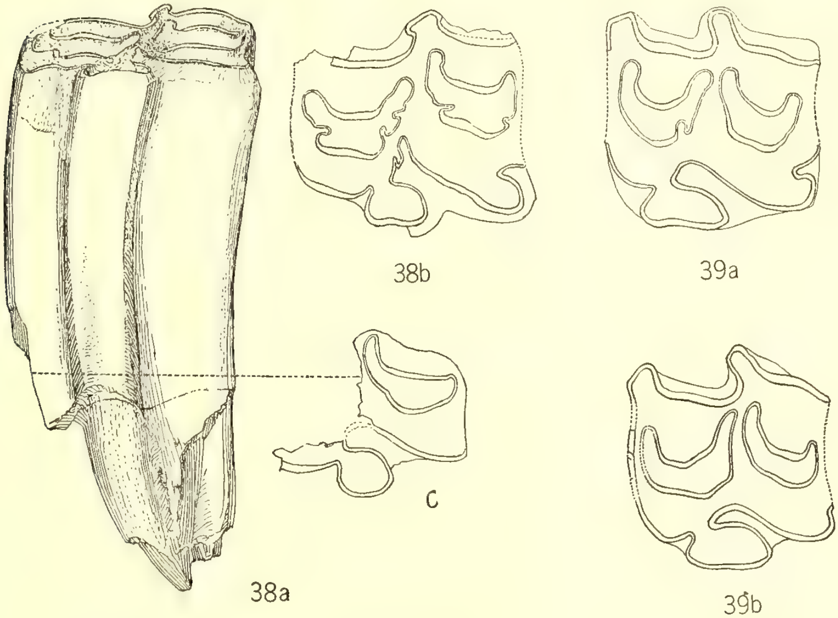
[25] Cope, E. D. Texas Geol. Surv., 1893; also Proc. Amer. Philos. Soc., vol. 30, 1892.

[26] Merriam John C. Relationship of Equus to Pliohippus, Suggested by Characters of a New Species from the Pliocene of California. Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 525–534, 1916.

Pliohippus francescana resembles the considerably smaller horse (see below) occurring in the same horizon: (1) in the general proportions of the protocone, slight amount of the projection of its anterior corner, and the circular protocone section of the premolars: (2) in the relative simplicity of the borders of the cement lakes. It differs markedly from the smaller form by the much greater size and accompanying heaviness of its styles as contrasted with the thin and slender ones of



Figs. 38*a* to 39*b*. *Pliohippus francescana minor*, n. subsp. Upper cheek teeth, × 1. Fig. 38*a*, P^3?, no. 23275, referred to type, inner view with section; fig. 38*b*, same tooth, occlusal view; fig. 39*a*, P^4, no. 23263 of type specimen, occlusal view; fig. 39*b*, M^1, no. 23264 of type specimen, occlusal view. San Timoteo beds, California.

the latter, the great size of its lakes, and the comparative broadness of the postprotoconal valley of M^1 and M^2 (*versus* the constriction of the same in the smaller form). The interesting similarity of the larger to the smaller series and their several strong points of common primitiveness point either: (1) to a parallel development of two distinct forms of advanced *Pliohippus* type associating in the same range; or (2) to an exceptional sexual variation. The writer has placed the small form, pending the securing of additional material, under the name *P. francescana minor.*

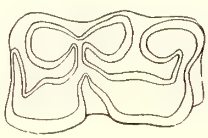
PLIOHIPPUS FRANCESCANA MINOR, n. subsp.

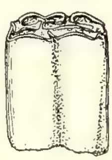
Folder 3, figure 3

Type.—Four closely associated upper cheek teeth, Univ. Calif. Coll. Vert. Pal. 23263, 23264, 23266, 23267 (folder 3, and figs. 39*a*–39*b*), representing(?) P^4 and M^1 of the left side, P^3 and M^1 of right side, Univ. Calif. loc. 3256.

Referred material.— To this species are referred an upper P^3(?), no. 23275 (figs. 38*a*–38*b*; folder 3, fig. 4, loc. 3264; a lower tooth, no. 23274 (figs. 40*a*–40*b*), loc. 3258; a small set of incisors in a portion of a premaxillary, no. 23347 (figs. 41*a*–41*b*), loc. 3256. All in Univ. Calif. Coll. Vert. Pal., all Univ. Calif. localities.

Characters.—The type is characterized by: (1) the relatively small size of the teeth and the marked lightness of the styles; (2) the very


40a


40b

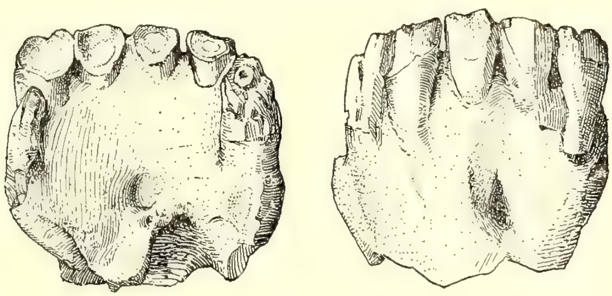
Figs. 40*a* and 40*b*. *Pliohippus francescana minor,* n. subsp. $P_{\overline{4}}$, no. 23274. Fig. 40*a*, occlusal view, × 1; fig. 40*b*, outer view, × ½. San Timoteo beds, California.

slight degree of anterior projection of the protocone, which is very slightly grooved on the inner surface in the premolars; (3) the constriction of the postprotoconal valley of the molars; (4) the narrow and relatively simple bordered fossettes; (5) the small dimensions of the primitively formed, referred lower tooth; (6) the small size of the referred premaxillary and incisors.

Description.—The upper cheek teeth of the type specimen (see folder 3, figs. 3*a*–3*e*) are considerably worn, with resulting very short-crowned appearance (they are in about the condition of wear of the *P. francescana* type and of the older Bautista series (see folder 3, fig. 1*a*; folder 2, fig. 3*a*). They are noticeably small, and are only moderately heavily cemented. The mesostyle is deep and remarkably narrow. The protocone is thick and rounded, with moderate antero-posterior diameter; in the premolars the inferior border is very slightly indented; in the molars it is elongated and somewhat flattened. The postprotoconal valley is comparatively narrow in the premolars, the walls are appressed in the molars where the anterior accessory fold of the valley is absent. The fossettes are extremely narrow, and have noticeably simple borders. The exterior wall of the paracone is flat,

that of the metacone tends to be convex instead of concave. Drawings (figs. 38*a*–38*b*) of the moderately worn triturating surface and of a deep cut section of a referred P^3(?) point to the following characters being due to a certain extent to age: (1) roundness of the protocone, (2) narrowness and simplicity of the fossettes, (3) absence of the post-protoconal folds.

The referred lower cheek tooth (figs. 40*a*–40*b*) is moderately worn. It is notably small. The groove of the metaconid-metastylid column is sharp but shallow. The wings of the column are moderately elongated and symmetrical. The fold between the protoconid and hypoconid is



41a 41b

Figs. 41*a* and 41*b*. *Pliohippus francescana minor,* n. subsp. Premaxillary with incisors, no. 23347, × ½. Fig. 41*a*, ventral view; fig. 41*b*, anterior view. San Timoteo beds, California.

broad and pointed, and does not reach the mouth of metaconid-metastylid. The exterior face of the hypoconid is flattened, while that of the protoconid is rounded. The entoconid is large and oval, as commonly the case in premolars.

The referred incisors (figs. 41*a*–41*b*) are small, evidently belonging to a form not larger than that represented by the upper teeth (compare Bautista, fig. 25).

Measurement of Type and Referred Teeth of Pliohippus francescana minor

	Type				Referred Specimens	
	No. 23266 P^3	No. 23263 P^4	No. 23264 M^1	No. 23267 M^1	No. 23275 P^3	No. 23274 Lower tooth
Anteroposterior diameter	31.8 mm.	(26.7) mm.	27 mm.	(26.3) mm.	30.3 mm.	26.8 mm.
Transverse diameter	29.7	29.4	28.8	29	28.7	15.1
Length of protocone	10	10.7	10.5	10.7	8.6	
Length of metaconid-metastylid column						14.9

Comparisons.—The small San Timoteo form is considerably more primitive than the heavier type specimens of *Pliohippus proversus,* differing markedly in: (1) the much lighter styles, as seen in the corresponding third premolars; (2) the anteroposterior shortness, the relative transverse thickness, and the generally pronounced convexity of the inferior border of its protocone; (3) the constriction of the posterior protoconal fold, and the narrowness of its anterior end.

The small upper teeth suggest a slightly more primitive form than *Pliohippus simplicidens* or *P. cumminsii* (Cope) of the Texas Blanco. The two former are unfortunately represented by very meager material. *P. cumminsii* is based on the type molar and the fragment of a second in the University of Texas Collection. *P. simplicidens* is known by the type specimen in the latter collection, by an upper tooth lacking the anterior portion of the protocone, by a referred P^{2} in the American Museum of Natural History, and by Professor Cope's referred lower series. A study of the type tooth of *P. simplicidens,* as shown in Professor Henry F. Osborn's reconstruction, and comparison with the specimens from the San Timoteo would tend to indicate through the following characters that the same is a P^{3}, not a molar as was originally stated: (1) the broad parastyle; (2) the short, thick, and round protocone, with slight concavity of the inner surface: (3) the prominence of the accessory fold of the postprotoconal valley; and (4) the superior position occupied by the anterior horn of the postfossette. Moreover, these same characters might be those of the P^{3} of such a series as that represented by the two type molars of *P. cumminsii.* The greater anteroposterior length of the *P. simplicidens* tooth, and the concavity of the inner edge of its protocone are only the usual distinguishing characters between premolars and molars. In short, a series thus compiled out of the *P. simplicidens* and *P. cumminsii* types would be similar to that of *P. francescana minor* in: (1) size; (2) the anteroposterior length of the protocone; (3) the simplicity of the fossette borders, and their strongly produced horns. It would differ from *P. francescana minor* in the relative breadth and thickness of its mesostyles, and in the broadness of the postprotoconal valley of the molar portion of the series.

The referred and slightly worn upper premolar (folder 3, fig. 4) bears a very interesting and remarkable resemblance to the type specimen of *P. osborni* from the underlying Eden horizon, as discussed in a following section. The small San Timoteo teeth in a less marked manner suggest the genus *Protohippus,* approximating the characters

given in Gidley's description of *P. sinus.*[27] They also approach *Pliohippus interpolatus* of Cope[28] (as seen in figures loaned by Professor Osborn) in the same tendency to narrowness of the styles and to constriction of the postprotoconal valley in the M^1 and M^2, but differ from figures of the molar of the less worn type specimen in the University of Texas Collection through lack of the greater degree of primitiveness shown in its smaller and rounder protocone. The fossettes of *P. interpolatus* are more complicated than those of *P. francescana minor.*

The single small lower tooth (no. 23274, fig. 40), is believed to represent the lower dentition of *P. francescana minor.* The slope of the exterior and interior faces refer it to the posterior portion of the series, while the very slight degree of prolongation of the fold between the protoconid and hypoconid place it not farther back than $P_{\overline{4}}$. In an $M_{\overline{1}}$ a similar lack of production in this fold would point to a degree of advancement beyond the usual in an equine of corresponding characters and size. The anteroposterior length of a $P_{\overline{4}}$ may be taken as 26% to 27% of the total length of $P_{\overline{3}}$ to $M_{\overline{2}}$ inclusive (in *E. occidentalis* of the Univ. Calif. Coll. Vert. Pal. no. 12258, the same figures 26%, in *P. simplicidens* of Cope's illustration 26%, and in *P. francescana* 27½%); this would place the total length of the four hypothetical lower teeth at 100 mm., a length which compares well with a compiled length of 108 mm. for the small uppers.

The specimen (figs. 40*a*–40*b*) is considerably smaller than the teeth figured in Professor Cope's lower series of *Pliohippus simplicidens.* Compared with the *P. simplicidens* series, and $P_{\overline{3}}$ in particular, the groove of the metaconid-metastylid column is a trifle more open; the prolongation of the interprotoconid-hypoconid fold is slightly less; the comparatively short parastylids are much the same; the protoconids have a certain resemblance in their exterior roundness, the present form exceeding *P. simplicidens* in this character; and the hypoconids are relatively flat.

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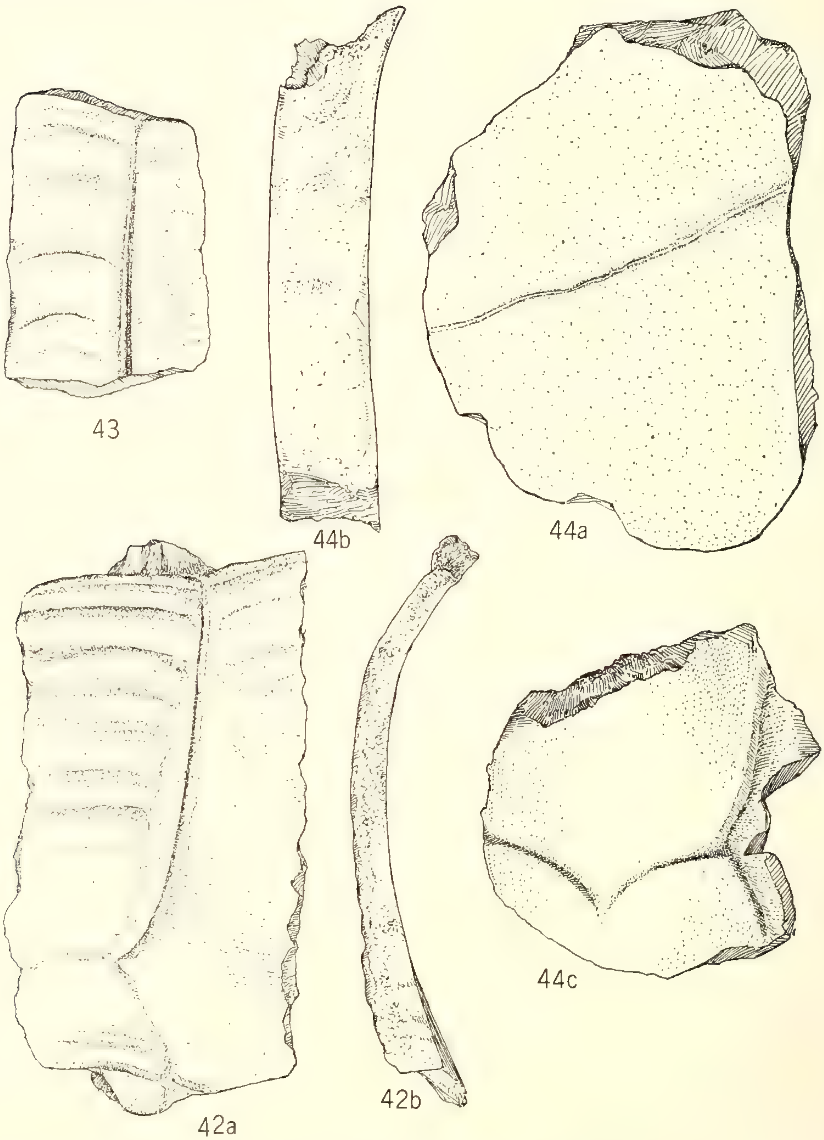
[27] Gidley, J. W. Revision of the Miocene and Pliocene Equidae of North America. Bull. Am. Mus. Nat. Hist., vol. 23, p. 925, 1907.

[28] Cope, Edw. D. Geol. Surv. Texas (1892), 1893.

TESTUDINATA

Material.—Large Testudo fragments, Univ. Calif. Coll. Vert. Pal. no. 23417 (figs. 42*a*, 42*b*). Smaller Testudo fragments, Univ. Calif. Coll. Vert. Pal. no. 23418 (figs. 43, 44*a*–44*c*).



Figs. 42*a* to 44*c*. Testudinate remains. Figs. 42*a*, 42*b*, no. 23417; figs. 43, 44*a*–44*c*, no. 23418; × ½. San Timoteo beds, California.

LOWER SAN TIMOTEO DEPOSITION, THE EDEN BEDS

Throughout a considerable area, in the southwest quarter of the Badlands, deposits characterized by greater induration and the prevalence of calcareous bluish and greenish shales appear unconformably underlying the San Timoteo beds. They are here designated as the Eden Formation (see fig. 1*c*; pl. 43, fig. 2; and pl. 44, figs. 3 and 4).

In its most northwesterly extension the Eden occurs in two low outcroppings of north-dipping, blue shales at the base of the west wall, a half mile above the mouth of Outlaw Cañon. At the opposite side of the same cañon the formation may be seen in north-and-south-dipping series in the cut for the new Rabbit Grade. The sharply north-dipping beds occupy a two hundred yard section along the road in the upper part of the first mile, the south-trending series being exposed for a quarter of a mile to the south. Southeastward the outcroppings of the Eden Formation may be followed for some five miles, across Eden Mountain, Laborda Cañon, and Lamb Cañon to the vicinity of the coarse underlying arkosics of the San Jacinto foothills and Lamb Mountain. The largest and finest exposures are to the immediate east of the Rabbit Grade, in the region about the western base and upon the higher northwestern corner of the mountain whose name has been given to the formation. There faulted ledges of indurated Eden sands and shales intermixed in lower planes with limestone breccia rest against the metamorphic limestone of the basement complex. These ledges have yielded much of the best material. They extend a fifth of a mile along the mountain face, and are capped by bluish shale slopes, thickly grown with brush. To the immediate east they disappear in the neighborhood of an overreaching arm of the San Timoteo formation. To the north and west they tumble cañon-ward and pass beneath the later deposits of the opposite hill-land.

The Eden beds in the Rabbit Cut lie in a sharp northeast- and southwest-dipping anticline unconformably overlain by similarly dipping beds of the San Timoteo deposit. The section is believed to represent the more general structure of the region. In the vicinity of the mountain itself the strata are much disturbed, the dips tending away from the schists. Immediately east of the Rabbit Cut the northeast dip is replaced by a northwestern. A particularly well marked break occurs in a 150-foot cliff in the hillside opposite the northwest corner of Eden, a forty foot ledge of dark indurated

sandstone intervening between the typical Eden shales and overlying San Timoteo. A similar indurated sandstone may be seen both a quarter of a mile to the south, capping an end of one of the typically low-lying blue ridges, and again above the blue Eden shales in the Rabbit Grade cut. The aspect of unconformity between the two San Timoteo formations has been generally heightened by faulting. The normal southwest dip of the southern limb occurs with certain interruptions throughout the area to the west and south of the mountain. The most noticeable interruption to this even trend away from the mountain schists is along the short northeast- and southwest-dipping fold occurring a sixth of a mile to the mountain's south. The same fold is limited eastward by a projecting spur of the mountain metamorphics. Beyond the spur sedimentary deposits again occur, here lying steeply inclined toward mounds of the complex, which have been faulted down. These mounds are separated from the monadnock by a small intervening valley. Eden-like deposits also extend over the central and southwestern portions of the mountain proper. An especially fine series of finely laminated beds lines the sides of an interesting and peculiar little valley that has been worn deep into the metamorphic limestone of the upper area.

The topography of the Badlands in the Eden locality differs from that farther west in the east and west *versus* north and south alignment of its cañons and ridges, through the Eden mountain mass having so far acted as an effective bar to southward erosion. From the north a view of the Eden region shows a long reach of brush grown slopes and ridges, and a tumbled brush-grown upland. From the south the view is of a schistose wall rising in rocky skyline from a low table land of sedimentary hillocks.

The denuded Eden scarp and the broken strata immediately to its south suggest a continuance near the mountain and valley intersection of the fault line, marked a short distance to the east in the high hanging and slicken-sided face of Claremont. The continuity of the same fault line westward is moreover suggested by the long line of springs in Reche Cañon and the steepness of the strata of the Moreno-San Timoteo edge.

Occurrence

Fossils have been found in place in the Eden in the following deposits:

1. In yellowish to greenish gray and somewhat micaceous sandstone.
2. In hard, bluish to greenish sandy shale.
3. In a particular calcareous sandy shale of variable texture.
4. In nodules of fine sandy clay of flint-like hardness.

No trace of fossil material was found about the well rounded and typical ridges of hard, compact, bluish-green shales, where the even surface and thin, downward-moving mantle of weathered gravels seemingly affords little opportunity for material to collect. At three localities nodules occurring in the neighborhood of interbedded ledges of sandstone and of hard nodular calcareous clays outcropping through ridges to west and southeast have been found to contain associated skeletal remains of individual camels.

The two localities which have yielded the greatest amount of the best fossil material, and which at the same time show the best sections, are: the exposure to the northwest side of the ravine, a fourth of a mile north of Eden Springs, near the contact with the brown-gray sandstone of the overlying formation; and the ledges on the shoulder of the mountain, one-half of a mile farther to the southeast. The Eden ravine section consists of massive sandstones in the creek bottom, followed by seventy feet of typical Eden deposits (light bluish-green shales, interbedded with layers of coarse to fine and clayey laminated sandstone and nodular calcareous clays) unconformably overlain by the lighter textured beds of the San Timoteo. The fossil material of this locality was traced through the wash, and dug from a tough, sandy shale of greenish-grey tinge. The matrix varied in texture from coarse to fine and floury, the finest containing quartz grains and small, rounded pebbles. The many rounded fragments of bone, and the small, flat stones lying in contact with more perfectly preserved fragments indicate the origin to be one of stream collection and deposition. This northwest-dipping section apparently stratigraphically overlies the more gently northwest- to horizontal-trending strata of the faulted ledges occurring on the mountain shoulder a half mile to the southeast, the same resting, as already mentioned, in direct contact with metamorphic limestone of the mountain complex. Lithologically the

two sections are similar in containing shales of the same general texture, similarly interstratified with bands of sandstone and nodular sandy clays; but the great outcroppings of mixed clayey sandstones are only visible in the ledges. Professor Louderback, who has very kindly made an analysis of some of this material, has reported as follows:

> The rock appears to carry no tuffaceous material, but is probably derived entirely from the erosion of the granitic terrane wih a subordinate amount of metamorphic rocks and some veining material. The fragments are not well rounded; some of the smaller ones are very irregular. All of the material excepting the very finest parts of the matrix is remarkably fresh and free from even partial weathering. The finest material is in part altered to clay, and there are some streaks of limonite here and there in the rock. The rock would correspond to unsorted finer grades of alluvial material developed under arid conditions, or at least under conditions where disintegration was in advance of weathering.

These hard ledges, especially their lighter colored, finer, and more calcareous layers, are at spots remarkably rich in fossilized teeth, bones, small shells, and particles of wood. The first fossils were found by the writer, minute bone fragments lying in open spots along the brush-grown top. Other material was later detected by his assistant in the weathered surface of the cliffs in process of decomposition and permeated with root hairs. There the main work was carried on by systematic excavation, great blocks of the rock being detached, carefully examined and broken open. Much good material was necessarily lost. Mining on a small scale was finally attempted by the aid of dynamite. The small amount of determinable material in the enormous quantity of the indurated matrix made the work very difficult.

Potrero Creek Deposits

It was mentioned above that southeastward the Eden formation rested upon arkosics of Lamb dome and the San Jacinto foothills. The arkosics of the Lamb region first appear at the mouth of Lime Kiln Cañon (lying to the immediate west of Lamb Cañon) in the form of a massive, south-dipping deposit of coarse, yellowish clay interstreaked with reddish arkose. The general eastern strike carries the section across Lamb Cañon, where it abuts against the granites and metamorphosed limestones of the Lamb Dome as well as against an intervening deposit of redder arkose, and thence to the adjoining valley of the Potrero lying at the foot of the outlying San Jacinto

hills. The red phase extends over the entire southern portion of the Potrero basin, whose water courses have cut deep channels in the heavily cemented mass. Northward, where the overlying Eden is again encountered, the upper beds are gray and finer. East of Potrero Creek the coarse deposit rests in magnificent, north-dipping exposures of alternating gray and reddish beds against the sides of Mount Claremont, rising to an altitude of 3500 feet.

One hypothesis suggests the correlation to these deposits with sandstones of the San Bernardino cañons to the north, which have been believed to be of Miocene age. No determinable material was secured in the short time devoted to this area.

Eden Fossil Localities where More Important Specimens were Collected

Altitudes barometrically checked (see fig. 1*c*)

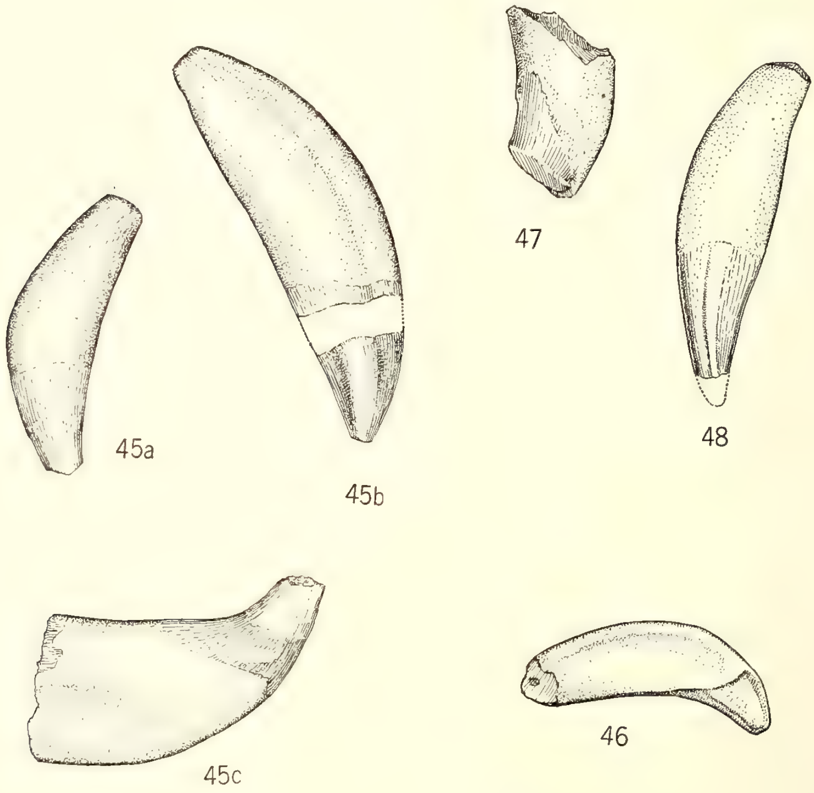
	Univ. Calif. loc.	
Mastodon station	3265	NE portion SW ¼ of Sec. 23, T. 3 S, R. 2 W.
Low diggings	3266	SE portion SE ¼ of Sec. 23, T. 3 S, R. 2 W; no. 11, fig. 1*c*.
Eden flats	3267	E portion NE ¼ of Sec. 23, T. 3 S, R. 2 W; no. 10, fig. 1*c*.
Eden flats, "B"	3268	W central portion of Sec. 23, T. 3 S, R. 2 W.
Eden ledges	3269	Central portion SW ¼ of Sec. 24, T. 3 S, R. 2 W; no. 12, fig. 1*c*.
Camel station no. 1	3270	SE portion SE ¼ of Sec. 24, T. 3 S, R. 2 W.
Lamb vertebrae	3271	SE portion NW ¼ of Sec. 32, T. 3 S, R. 1 W; no. 13, fig. 1*c*.
Potrero clay	3272	SW ¼ of NE ¼ of Sec. 4, T. 4 S, R. 1 W.
Camel station no. 3	3273	SW ¼ of NW ¼ of Sec. 30, T. 4 S, R. 1 W.
Potrero	3274	NE ¼ of NE ¼ of Sec. 33, T. 3 S, R. 1 W.
Potrero	3275	W central portion of NW ¼ of Sec. 34, T. 3 S, R. 1 W, no. 14, fig. 1*c*.

Description of Eden Pliocene Fauna

The distance of the Eden type locality from hitherto described deposits of the Western Hemisphere yielding Pliocene mammalia, immediately suggests the possibility of the Eden life representing a new geographic phase. The following studies, the consideration of the Eden material as a whole, and the comparisons of the more fully represented forms with those of the other known assemblages of the Pliocene point to this assemblage as representing a new phase of late Lower Pliocene life.

The Eden fauna as at present known is as follows:

Canis?, sp.
Felis?, sp.
Smilodon?, sp.
Hyaenarctos gregoryi, n. sp.
Hypolagus edensis, n. sp.
Nothrotherium? or Pronothrotherium?, sp.
Megalonyx?, sp.
Prosthennops edensis, n. sp.
Platygonus?, sp.
Pliauchenia merriami, n. sp.
Pliauchenia, sp. A
Procamelus edensis edensis, n. sp.
Procamelus edensis raki, n. var.
Procamelus, n. sp., cervus-like
Procameline, indet. sp.
Cervid, sp.
Merycodus? or Ilingoceros?
Antilocapra?, sp.
Pliohippus osborni, n. sp.
Pliohippus osborni, subform A
Pliohippus edensis, n. sp.
Pliohippus edensis, subform A
Pliohippus edensis, subform B
Trilophodon shepardi edensis, n. subsp.
?Avian remains
Fish and shells



Figs. 45*a*–45*c*, 46–48. *Canis?*, *Smilodon?*, and *Felis?*, sp. Canine and incisor teeth, × 1. Fig. 45*a*, *Canis?*, upper canine, no. 24019; fig. 45*b*, *Canis?*, upper canine, no. 24020; fig. 45*c*, *Canis?*, lower canine, no. 24021; fig. 46, *Smilodon?*, sp., I², no. 24024; *Felis?*: fig. 47, upper canine, no. 24022; fig. 48, upper canine, no. 24023. Eden beds, California.

Canidae

CANIS? AND FELIS?

The collections from the Eden include two upper and one lower canine tooth of stout, dog- or wolf-like form, Univ. Calif. Coll. Vert. Pal. nos. 24019, 24020, and 24021 (figs. 45*a*–45*c*); and two upper canines of more slender character possibly referable to *Felis*, Univ. Calif. Coll. Vert. Pal. no. 24022 (fig. 47) and no. 24023 (fig. 48), loc. 3269.

SMILODON?, sp.

A third upper incisor, Univ. Calif. Coll. Vert. Pal. no. 24024 (fig. 46), Univ. Calif. loc. 3269, recalls the well marked ridge or heavy cingulum occurring characteristically in the sabre-toothed group, the specimen evidently representing some one of the smaller forms.

Ursidae

Until of late very little has been known of the history of the bears in America previous to Pleistocene time and the appearance of *Arctotherium* and *Ursus*. While *Ursus* is believed to have been a late emigrant of eastern origin, *Arctotherium*, which is unrepresented in the collections of the Old World, is considered to be an American development of an earlier arrival of more primitive European stock. The presence of such a pre-Pleistocene bear in the Western Hemisphere was first suggested in 1910 by Dr. Freudenberg[29] on the discovery in the Tehuichila of Mexico of a large lower carnassial of hyaenarctid character. More recently the occurrence in the American Pliocene of several primitive bear forms has been definitely determined through the separate researches of Messrs. Sellards, Merriam, and Barbour, who have named three different forms:

Agriotherium (*Hyaenarctus*) *schneideri* Sellards,[30] based on a lower mandible from the Bone Valley formation of the Florida Alachua.

Indarctos oregonensis, Merriam, Stock and Moody,[31] based on the incisors, canines, P^4 and M^2 of the upper jaw, and M_2 of the lower, as well as portions of associated limb bones from the Rattlesnake.

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29 Freudenberg, W. Geo. Palae. Abh., N. F. Bd. 9, 1910.

30 Sellards, E. H. 8th Ann. Rept. Florida State Geol. Surv., 1916.

31 Merriam, John C., Stock, Chester, and Moody, C. L. An American Pliocene Bear. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 87–109, 1916.

Dinarctotherium merriami Barbour[32] from a giant humerus in the Nebraska University collections.

In the following pages the author describes a fourth American Pliocene bear from two upper carnassials and a first upper molar, collected in the Eden by his assistant, Mr. Rak. This is the first discovery of an ursid M^1 in American deposits of early Pliocene age. The carnassials associated with this specimen make possible a definite comparison with the splendid Rattlesnake material.

HYAENARCTOS GREGORYI, n. sp.

Type.—A worn upper carnassial tooth from the left side of the jaw, Univ. Calif. Coll. Vert. Pal. no. 24025 (figs. 49*a*, 49*b*), Univ. Calif. loc. 3269.

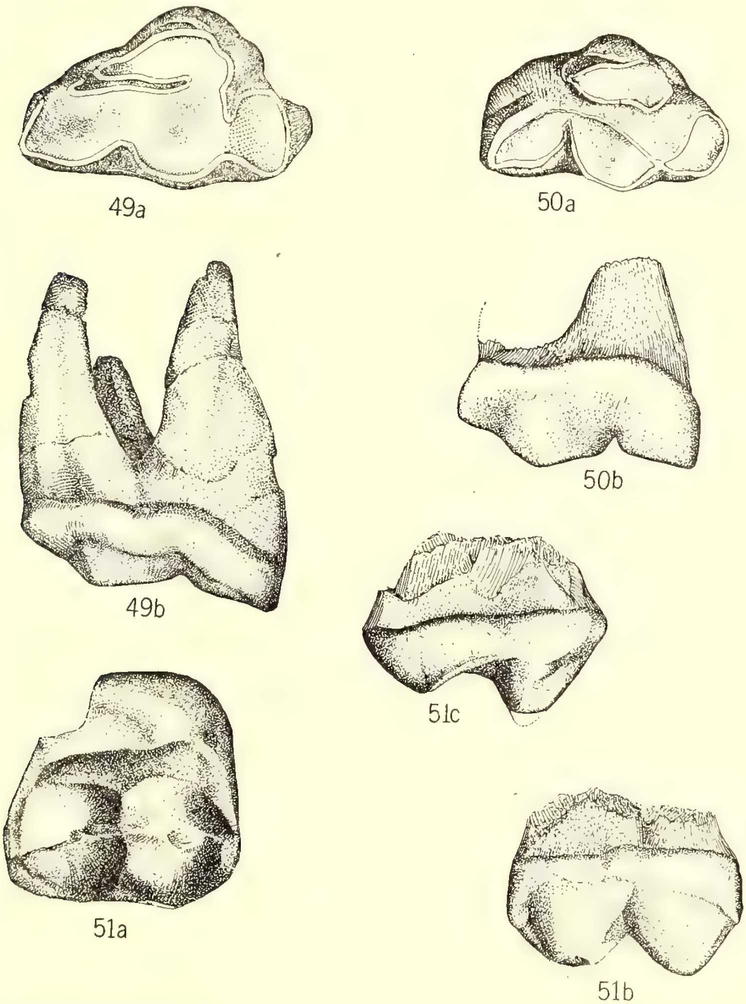
Referred material.—The material referred to this species consists of an upper first molar from the left side, Univ. Calif. Coll. Vert. Pal. no. 24026 (figs. 51*a*–51*c*), and a somewhat smaller upper carnassial from the left side, Univ. Calif. Coll. Vert. Pal. no. 24027 (figs. 50*a*, 50*b*); both from the same general locality as the type specimen.

Characters.—The unusually large size of the protostyle, the direct anterior position of the same in relation to the protocone; the anterior extension and the anteroposterior length of the deuterocone; the lack of a marked external cingulum in the referred M^1, the central position of the inner ridge of this tooth in relation to the imaginary line of the main cusps and that of the interior tooth margin, and the marked diagonal direction of the same inner ridge.

Description.—The anteroposterior diameter of the type carnassial (no. 24025, figs. 49*a*–49*b*) is 1.33 times the greatest transverse diameter. The tooth evidently belongs to an old individual, the lobes having been considerably worn away. A single, deeply worn, indented surface now joins the two main posterior cusps (tritocone and protocone) to the third but slightly smaller cusp, lying directly anterior to the two first (the protostyle, or ''talon'' of Dr. Lydekker), and to the elongate cusp which is appressed against the inner margin of the first two (the deuterocone). At the anterior extremity of the tooth the edge of the downward-sloping triturating surface cuts the top of the root. A cingulum follows the external contour, which, generally convex, becomes slightly concave opposite the anterior and posterior extremities of the protocone. A heavier cingulum crosses the inner margin of the deuterocone. A constricted, anteriorly directed valley separates

[32] Barbour, E. H. Neb. Geol. Surv., vol. 4, pp. 349–353, 1916.

the hinder two-thirds of the protocone from the backward-sweeping deuterocone. A strong, forwardly directed fang supports the tritocone and the posterior portion of the protocone; a more massive, forwardly directed root supports the anterior portion of the latter cone and the adjoining protostyle; and a third, inner, and more slender fang supports the deuterocone.



Figs. 49*a*–49*b*, 50*a*–50*b*, 51*a*–51*c*. *Hyaenarctos gregoryi*, n. sp. Upper teeth, × 1. Figs. 49*a*, 49*b*, P^4, no. 24025, type occlusal and outer views; figs. 50*a*, 50*b*, P^4, no. 24027, referred, occlusal and outer views; figs. 51*a*–51*c*, M^1, no. 24026, referred, occlusal, outer, and anterior views. Eden beds, California.

First molar.—The referred first molar (no. 24026, figs. 51*a*–51*c*) is little worn. The anterior inner corner of the specimen is broken, and the tip of the main posterior cusp is missing. The transverse width of this tooth is slightly more than the anteroposterior, which is greatest externally. The specimen is furnished with two strong, pyramidal-shaped outer cones, the paracone and metacone, and a low, diagonally directed, inner ridge, which slopes outward and upward from the inner posterior margin of the tooth border, and is divided from the main cones by a broad valley. This ridge at its central point is equidistant from the tooth's inner border and an imaginary line joining the tips of the main cones. A slight rugosity of the exterior side of the specimen takes the form of cingula at its slightly projecting posterior, and at its squared anterior corners, where the cingulum is the most prominent. These anterior and posterior cingula are joined laterally by wings from the inner ridge. A very slight concavity occurs in the external border opposite the valley that divides the two main cones. The mid-anterior extremity of the tooth, unlike the mid-posterior margin, is slightly indented. The specimen apparently had three roots, two outer and one inner.

Small carnassial.—In its small size this tooth (no. 24027, figs. 50*a*, 50*b*), differs markedly from the type specimen. It is considerably less worn than the first carnassial, a wide valley still separating the deuterocone from the outer main cones. The protostyle lies directly anterior to the protocone, as in the large specimen, and the proportions of the cusp are similar to those of the first tooth. This smaller referred tooth is at present believed to represent no more than a marked sexual variation, being in general form and relative proportion in all respects identical with the type specimen. In its well preserved and unworn state the normal tooth pattern is readily seen, the characters supporting those noted in the larger tooth as follows: (1) the unusual size of the protostyle which almost equals that of the protocone; (2) the considerable anterior projection of the deuterocone; (3) the outer and strong inner cingula; (4) the great relative size of the posterior root, and the proportionate narrowness of that of the tritocone.

COMPARATIVE MEASUREMENTS

	Type Univ. Calif. Coll. Vert. Pal. 24025	Referred Univ. Calif. Coll. Vert. Pal. 24027	H. sivalensis	H. punjabiensis	Indarctos oregonensis	H. palaeindicus
P^4, greatest anteroposterior length..	34.4 mm.	32.3 mm.	32.9 mm.	31.5 mm.	31.7 mm.	
P^4, greatest transverse width	25.8	21.7	19.7	22.2	22.6	
P^4, greatest height of crown	11.3	12.9			11.4	
		Univ. Calif. Coll. Vert. Pal. 24026				
M^1, greatest anteroposterior length..		30.6	30.4	29.8		27.5 mm.
M^1, greatest transverse width		32.2	26.5	27.3		26.4
M^2, greatest anteroposterior length..			27.9		25.3	30
M^2, greatest transverse width			30.4		26.8	19.2

Comparisons.—The teeth differ from those of the modern bears, and show the following hyaenarctid affinities:

1. A large tubercle (protostyle) is present in the tooth anterior to the protocone, this tubercle being absent in *Ursus* and corresponding to that of the hyaena (it is suggested in some specimens of *Arctotherium*).

2. The position of the inner tubercle (deuterocone) is median and anterior, instead of posterior as in the bears, thus approaching that of the dogs. The inner tubercle is also larger than in *Ursus*, and is proportionately larger than in *Arctotherium.*

3. The carnassial is three-rooted, instead of two-rooted as in the bear.

4. The carnassial is longer anteroposteriorly than the (referred) M^1.

5. The referred first molar is a little broader than long anteroposteriorly, thus somewhat resembling *Arctotherium* and differing from *Ursus,* in which the corresponding tooth is oblong.

Compared to *Hyaenarctos sivalensis*[33] the present specimens while generally resembling the same, specifically differ as follows: (1) the type tooth is larger (see table of measurements) and the ratio of its length to breadth is 1.33 *versus* 1.8 *in H. sivalensis;* (2) the protostyle is much larger, and it is placed directly in line with and anterior to the two main cusps, resulting in giving the tooth a more even external

[33] Lydekker, R. Indian Tertiary and post-Tertiary Vertebrata. Mem. Geol. Surv. India, ser. 10, vol. 2, pp. 220–225, 1884.

contour; (3) the deuterocone is considerably more developed and reaches much farther forward, the base of the tooth at its anterior edge sweeping inward from the adjoining base of the protostyle instead of forming a sharp angle with the mid-wall of the protocone as in *H. sivalensis;* (4) the referred $M^{\underline{1}}$ is larger than the corresponding tooth of *H. sivalensis,* and the ratio of anteroposterior and transverse diameters are unlike, being .95 in the Eden specimen and 1.15 in *H. sivalensis;* (5) the direction of the inner ridge is more oblique to the inner tooth margin than is apparently the case in *Hyaenarctos sivalensis,* and the inner ridge at its mid-point is proportionately much farther from the inner tooth margin than in *H. sivalensis;* (6) the external faces of the main cusps are more vertical, and lack the well developed cingulum; the outer tooth contour also lacks the deep mid-indentation seen in *H. sivalensis.*

Compared to *Hyaenarctos punjabiensis:*[34] The carnassial of the unworn series of *H. punjabiensis* illustrated by Dr. Lydekker is narrower and lighter than the present type specimen, and differs from it very markedly in the small size of its protostyle and more feeble development of its tritocone. In two minor characters, on the other hand, (1) the more even contour of the external base, due to the more similar anterior position of the protostyle, and (2) the apparently greater development of the deuterocone, *H. punjabiensis* resembles the new specimen more than does *H. sivalensis.*

Compared to the first molar of *Indarctus salmontanus:*[35] The $M^{\underline{1}}$ referred to the new specimen is slightly broader than long anteroposteriorly, and thus differs somewhat widely from the *I. salmontanus* $M^{\underline{1}}$, which is distinctly longer than broad. $M^{\underline{1}}$ of *I. oregonensis* is not known.

The $P^{\underline{4}}$ of *I. salmontanus* and the $P^{\underline{4}}$ of *Indarctos oregonensis*[36] bear no very close resemblance to the carnassial of *H. gregoryi,* and differ from it more markedly than does *H. sivalensis:* (1) the protostyle of *I. oregonensis* is even less developed than in *H. sivalensis,* and its position is fully as internal; (2) the deuterocone is produced anteriorly even less than in *H. sivalensis;* (3) the deuterocone occupies considerably more of the transverse width of the tooth than in either the present specimen or in *H. sivalensis.*

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[34] Lydekker, R. *Op. cit.,* pl. 30, fig. 2.

[35] Pilgrim, Guy E. Records Geol. Surv. India, vol. 44, pp. 225–233, pl. 20, 1914.

[36] Merriam, Stock, and Moody. *Op cit.,* pp. 91–93, 1916.

The teeth of *H. gregoryi* are much larger than those of Dr. Lydekder's *H. palaeindicus,* which are perhaps more *Hemicyon*-like than *Hyaenarctos*-like in the shortness of the M^1 and the great roundness of the inner tooth angles. On the other hand, in certain minor characters the *H. palaeindicus* M^1 as compared with *H. sivalensis* is nearer the present species: (1) in the apparently greater development of the protostyle and in the more anterior position of the basal region of the deuterocone of the carnassial; (2) in the abruptnes of the main cone above the outer tooth margin, in the apparent lack of a marked external cingulum, and the greater distance of the inner ridge from the inner tooth margin of the first molar.

The *Hyaenarctos* from the Red Crag, represented in a first superior molar, is shown by Lydekker (*loc. cit.*) to be specifically different from the M^1 of *H. sivalensis,* though very similar in general tooth outline, well marked external cingulum, and bold outer cones. In the relatively considerable distance of the inner ridge from the inner tooth border the Eden specimen and the Red Crag specimen agree in differing from *H. sivalensis.*

The carnassial of the much smaller *H. insignis,* described by Gervais from the Montpellier of France, differs more widely from the Eden form than does *H. sivalensis.*

Summary.—The Eden fauna contained a very large bear with a dentition of strong hyaenarctid character. The teeth differ specifically from all previously described forms. They resemble more closely *Hyaenarctos sivalensis* (*H. punjabiensis* and *palaeindicus* only in minor characters) of the Indian Pliocene than any American species so far known. A smaller and closely allied form is suggested by a second carnassial, of smaller size. The difference in size, however, may be merely a sex character, such a difference being very marked in some of the living bears. On the other hand, the occurrence of a number of allied forms is to be expected should the Western Hemisphere indeed have given rise to the arctothere group.

Lagomorpha

HYPOLAGUS EDENSIS, n. sp.

Type.—A fragment of the left mandible containing $P_{\overline{3}}$, $M_{\overline{1}}$, and $M_{\overline{2}}$, no. 23376 (fig. 52), Univ. Calif. loc. 3269. Specimens tentatively referred to this species are the portions of a premaxilla holding an incisor, no. 23375 (fig. 53), and a small astragalus, no. 23377 (fig. 54), both from the same general locality as the type. All specimens in Univ. Calif. Coll. Vert. Pal.

Characters.—The depth of the two valley-like infoldings of the exterior side of $P_{\overline{3}}$, the posterior of the two extending slightly over half way across the crown.

52

54

53

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Fig. 52. *Hypolagus edensis,* n. sp. $P_{\overline{3}}$, $M_{\overline{1}}$, and $M_{\overline{2}}$, no. 23376, outer and occlusal views, × 2.

Fig. 53. *?Hypolagus edensis.* Incisor, no. 23375, × 1.

Fig. 54. Lagamorph astragalus, no. 23377, × 3.

Fig. 55. Avian phalanx, no. 599, × 2.

All specimens from Eden beds, California.

Description and comparison.—The specimen has the genral character of the genus *Hypolagus* as given by Dr. L. R. Dice;[37] it differs from the type species, *H. vetus* Kellogg, by the depth of the two infoldings of the exterior tooth surface of $P_{\overline{3}}$. A single deep infolding, as in *H. vetus,* occurs in the exterior side of the associated molars. The inner sides of the teeth are rounded and lack the reëntrant angles seen in *H. vetus.* The anterior portions of the crowns are higher than the posterior.

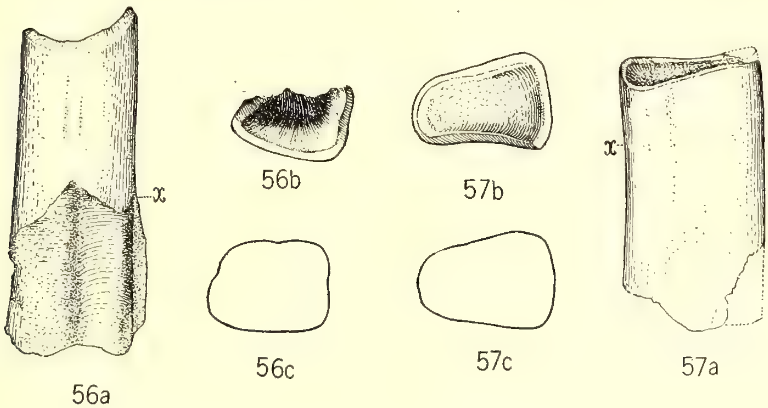
Measurements of Type Dentition, No. 23376

$P_{\overline{3}}$, greatest anteroposterior diameter	2.4 mm.
$P_{\overline{3}}$, greatest transverse diameter	2.1
$M_{\overline{1}}$, greatest anteroposterior diameter	2
$M_{\overline{1}}$, greatst transverse diameter	2.2
$M_{\overline{2}}$, greatest anteroposterior diameter	2.1
$M_{\overline{2}}$, greaetst transverse diameter	2.2

37 Dice, L. R. Systematic Position of Several American Tertiary Lagamorphs. Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 181–183, 1917.

EDENTATA

Two specimens from the Eden, which according to Dr. Stock have undoubted megalonychid and possibly nothrothere characters, are of great interest, suggesting the earliest known occurrence of the two genera in North America. Both *Nothrotherium* and *Megalonyx* are of frequent occurrence in the California Pleistocene, but neither have heretofore been recognized in North America in so early a formation as the mid-Pliocene. A genus, *Pronothrotherium,* has been described



Figs. 56*a*–56*c*, 57*a*–57*c*. *Nothrotherium?* or *Pronothrotherium?,* sp. Edentate cheek teeth, × 1. Figs. 56*a* to 56*c*, no. 23374; figs. 57*a* to 57*c*, *Megalonyx?,* sp., no. 23371. Eden beds, California.

from the Pliocene of South America, and *Megalonyx leptostomus* Cope from the Blanco Pliocene of Texas. The present collection from the overlying San Timoteo also includes a tooth of *Megalonyx* type, as shown above.

NOTHROTHERIUM? OR PRONOTHROTHERIUM?, sp.

Material.—A cheek-tooth, Univ. Calif. Coll. Vert. Pal. no. 23374 (figs. 56*a*–56*c*), Univ. Calif. loc. 3269.

Description.—Though one side of the triturating surface is damaged the unbroken walls of the tooth (fig. 56*c*) show the transverse diameter of the crown to have been under twice that of its antero-posterior diameter. The triturating surface is deeply concave, its transverse crests being furnished with beveled edges. A medium vertical groove on both the outer and inner surfaces tends to divide

the tooth transversely into an anterior and a posterior half. This character is commonly developed in teeth of *Nothrotherium,* the groove being absent in *Hapalops* of the South American Miocene. While the tooth considerably resembles the two anterior cheek teeth of the lower jaw in *Nothrotherium* of the California Pleistocene, the species which this tooth must represent would be so far removed in time from the latter that the specimen (no. 23374) may have been of either the upper or lower series.

MEGALONYX(?), sp.

Material.—A cheek-tooth Univ. Calif. Coll. Vert. Pal. no. 23371 (figs. 57*a*–57*c*), Univ. Calif. loc. 3269.

Description.—The tooth is considerably larger than the foregoing specimen, and greatly different in form: (1) in the relative broadness and narrowness of its transverse extremities, (2) in the roundness of the inner and outer corners, and (3) in the lack of the marked tendency to transverse subdivision into anterior and posterior halves. The specimen is somewhat larger than that of the megalonychid specimen (no. 23373, figs. 29*a*–29*b*) from the overlying formation and its triturating surface is differently worn. Except for its slightly smaller size the tooth resembles a tooth of *Megalonyx* from the Potter Creek Cave. The Eden specimen might represent either the second or third tooth of the upper jaw.

MEASUREMENTS

	No. 23374	No. 23371
Greatest transverse diameter of molar crown	11.6 mm.	18.8 mm.
Greatest anteroposterior diameter of molar crown	15.8	12.3

DICOTYLINAE

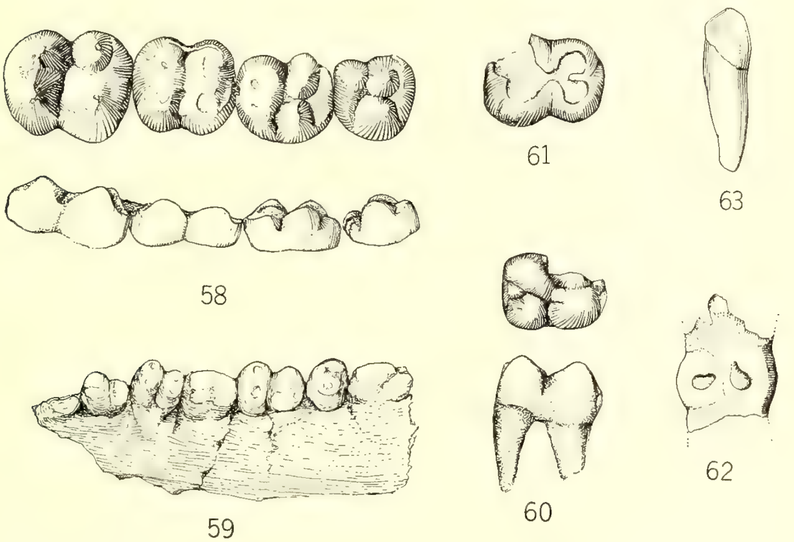
The collection contains specimens of upper and lower cheek teeth and canines. The cheek teeth are of definite *Prosthennops* character. The canines are believed to be too large for association with the other teeth, or inclusion within the genus *Prosthennops* as at present defined. They are tentatively referred to *Platygonus.*

PROSTHENNOPS EDENSIS, n. sp.

Type.—P^3 to M^2 contained in a fragment of the maxillary (fig. 58), Univ. Calif. Coll. Vert. Pal. no. 23369, Univ. Calif. loc. 3269.

Referred specimens.—Fragmentary lower series, including $P_{\overline{3}}$ to $M_{\overline{3}}$, and showing the alveolus of $P_{\overline{2}}$, no. 23370 (fig. 59); a premolar, no. 23776 (fig. 60); a worn upper cheek tooth, no. 23777 (fig. 61); a portion of a third lower molar, no. 23775 (fig. 62); and a small incisor, no. 23788 (fig. 63). All Univ. Calif. Coll. Vert. Pal.; all from Univ. Calif. loc. 3269.

Generic and specific characters.—The low crowns and the tendency of the patterns to be multicuspid. The small size and but partial molariform character of the third premolar.



Figs. 58 to 63. *Prosthennops edensis*, n. sp. Upper and lower teeth. Fig. 58, type specimen, $P^{\underline{3}}$ to $M^{\underline{2}}$, no. 23369, occlusal and lateral views, × 1. Referred specimens: fig. 59, fragment of mandible with cheek tooth series, no. 23370, × ½; fig. 60, $P_{\overline{3}}$, no. 23776, lateral and occlusal view, × 1; fig. 61, upper molar, no. 23777, occlusal view, × 1; fig. 62, fragment of $M_{\overline{3}}$, no. 23775, occlusal view, × 1; fig. 63, incisor, no. 23788, × 1. Eden beds, California.

Description.—The crowns of the teeth of the type specimen, fig. 58, are well preserved. The two premolars are very little worn in comparison with the first molar. The second molar is much larger than the first, and shows posteriorly an even greater development than in $M^{\underline{1}}$. Anteriorly the teeth are bordered by cingula-like shelves, which are most prominent in the premolars. The shallow transverse valleys between the paired anterior and posterior cusps are continuous and scarcely interrupted by conules that occur within the pairs, tending to connect each in a primitive transverse crest. The inner edges of the crests are somewhat produced.

COMPARATIVE TOOTH MEASUREMENTS

	Eden, No. 23369 Prosthennops edensis, n. sp.	Thousand Creek, No. 2744	Rattlesnake, No. 3060
P^3, greatest anteroposterior diameter	9.5 mm.	10.9 mm.	12 mm.
P^3, greatest transverse diameter	9	11.2	9.6
P^4, greatest anteroposterior diameter	13	12.4	12.7
P^4, greatest transverse diameter	10.5	12.6	11
M^1, greatest anteroposterior diameter	13		14
M^1, greatest transverse diameter	11.5		11.7
M^2, greatest anteroposterior diameter	16.6		
M^2, greatest transverse diameter	15		

Comparisons.—The teeth are larger and more bunodont than those of a *Prosthennops*-like form from the Rattlesnake[38] that furthermore shows certain *Platygonus* characters in the height of the crown, tendency to more marked separation of the anterior and posterior crests, and triangularity of the P^3 (Univ. Calif. Coll. Vert. Pal. no. 3060).

The generally greater length of the cheek-tooth row and the more progressive stage evidenced in the complete molariform character of the last premolar, both in size and shape, are in contrast to the more primitive *Prosthennops crassigenis* of the South Dakota Upper Miocene, as illustrated and described by Dr. W. D. Matthews,[39] "Premolars much smaller than the molars; . . . P^3 and P^4 four-rooted, but not completely molariform . . ."

Prosthennops-like specimens of P^3 and P^4 from Thousand Creek differ from the Eden forms in the presence of posterior and lateral cingula in P^3 and a posterior accessory tubercle in both P^3 and P^4; also in the absence of the anterior shelf-like cingula seen in the Eden species. The Thousand Creek specimen (Univ. Calif. Coll. Vert. Pal. no. 2744), furthermore, shows a certain advance over the Eden form in the even greater development of the molariform P^3.

Upper jaw referred material.—Upper cheek tooth, Univ. Calif. Coll. Vert. Pal. no. 23777 (fig. 61) is of premolar form. The pattern is too worn to permit a specific determination, the four tubercles being replaced by an irregular confluent depression, embraced by higher and more resistant enamel of the unworn reëntrant valleys and tooth margin. There is evidence of a cingulum anteriorly and at the middle of the inner side of the tooth. The specimen measures 11 × 6.5 mm.

[38] From unpublished manuscript, by courtesy of Professor John C. Merriam.

[39] Matthew, W. D., and Gidley, J. W. New and Little Known Mammals from the Miocene of South Dakota. Amer. Museum Expedition of 1903. Bull. Am. Mus. Nat. Hist., vol. 20, p. 265, 1904.

Lower jaw referred material.—The lower jaw specimen shown in figure 59 (Univ. Calif. Coll. Vert. Pal. no. 23370) has been reconstructed from disintegrating fragments which were found held together in crumbling rock. The triturating surfaces of several of the teeth are too far gone for accurate description. $P_{\overline{3}}$ is small and tricuspid, and $P_{\overline{4}}$ completely molariform, thus resembling the $P^{\underline{4}}$ of the type upper jaw (no. 23369). The slightly greater proportionate size of the teeth admits of but tentative reference to the upper series.

A small, newly erupted tooth (Univ. Calif. Coll. Vert. Pal. no. 23776, fig. 60) is very similar in form and size to $P_{\overline{4}}$ of the lower series (no. 23370). Greatest anteroposterior and transverse diameters measure 13.7 mm. and 10.3 mm. It is low-crowned and four-rooted. The four rounded main cusps are divided into a posterior and a slightly higher anterior pair, of which the anterior external corner is broken. Three small accessory tubercles lie respectively at the mid-posterior and mid-anterior extremities, and in the main transverse valley. There is a slight suggestion of cingula in connection with the anterior tubercle and the outer end of the main transverse valley.

Measurements of Lower Teeth Referred to Prosthennops edensis, n. sp.

	No. 23370	No. 23776
$P_{\overline{3}}$, greatest anteroposterior diameter	10 mm.	13.7 mm.
$P_{\overline{3}}$, greatest transverse diameter	7	10.3
$P_{\overline{3}}$, height of crown		8.5
$P_{\overline{4}}$, greatest anteroposterior diameter	13	11.
$P_{\overline{4}}$, greatest transverse diameter	10.3	6.5
$M_{\overline{1}}$, greatest anteroposterior diameter	13.7	
$M_{\overline{1}}$, greatest transverse diameter	15.5	
$M_{\overline{2}}$, greatest anteroposterior diameter	16.5	
$M_{\overline{2}}$, greatest transverse diameter	11.2	No. 23775
$M_{\overline{3}}$, greatest anteroposterior diameter	(27)	
$M_{\overline{3}}$, greatest transverse diameter	13	13.6
$M_{\overline{3}}$, height of crown		6.7

Comparisons.—The lower premolar specimen (no. 23776) lacks the high, paired cones, and the deep, uninterrupted transverse valley of the genus *Platygonus.* Superficially it somewhat resembles $P_{\overline{3}}$ of *Mylohyus* from the Conard Fissure,[40] but differs through its much smaller size, and the considerably less pronounced development of

[40] Brown, Barnum. The Conard Fissure, a Pleistocene Bone Deposit in Northern Arkansas: With Descriptions of Two New Genera and Twenty New Species of Mammals. Mem. Am. Mus. Nat. Hist., vol. 9, pl. 24, 1908.

the posterior and mid-central tubercles. The specimen is, on the other hand, larger than the $P_{\overline{3}}$ of a series figured by Dr. Matthew from the Pliocene of western Nebraska, which is referred to *Prosthennops crassigenis.*[41] The specimen approximates in size $P_{\overline{4}}$ of the Nebraska series, but lacks the latter's well developed, posteroexternal cingulum and height in the anterior cones. *P. serus* is stated to be larger than *P. crassigensis.*

No. 23776 has somewhat the general appearance of an $M_{\overline{2}}$ from the Merychippus zone of Coalinga,[42] measuring 26.2 mm. by 15.9 mm. though lacking in the molariform characters of heel and large external cingulum.

Specimen no. 23776 is without the development of the tubercles of the inner side as well as the anterior and large posterior shelves. and is more strongly bunodont than a $P_{\overline{3}}$ from the Rattlesnake referred to *Prosthennops,* which measures 16 mm. anteroposteriorly by 11 mm. transversely. A great dissimilarity between these two forms has been noted already in the comparison of the upper teeth.

Lower cheek tooth, no. 23775 (fig. 62), possesses a central pair of transverse cones lying between portions of an anterior and of an inflected posterior pair. The specimen evidently represents the last molar. It is low-crowned, and the shallow transverse valleys are without accessory tubercles. The tooth apparently corresponds in size with the last molar of the lower jaw series (no. 23370).

PLATYGONUS?, sp.

Material.—A large canine, no. 23439, and a much more slender canine of equal length, no. 23440, both from the lower left side of the jaw (figs. 64, 65), Univ. Calif. loc. 3269. Both specimens in Univ. Calif. Coll. Vert. Pal.

Description.—The larger specimen (no. 23439) is robust, triangular in cross-section, and well recurved. The narrow anterior edge is somewhat rounded. A flat, sharp-edged surface is worn into the posterior side and cuts diagonally across the alveolar portion. The inner side is slightly grooved, and is narrower than the outer. The outer side is marked along the median line by a well defined swelling which is continuous with the root. A corresponding groove occurs on the inner side, and is discernible in the root but is interrupted in the region of the alveolus.

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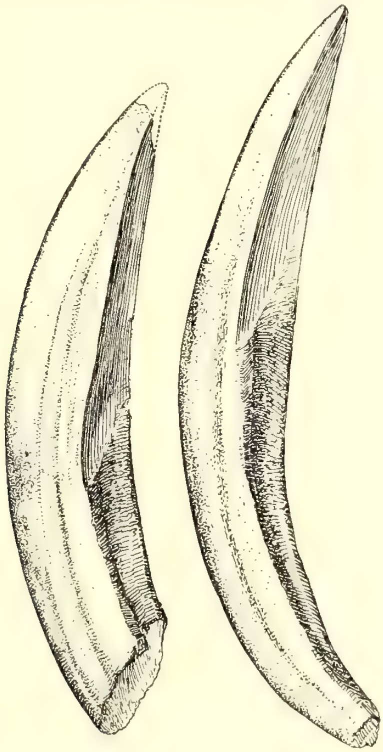
41 Matthew, Wm. D., and Cook, Harold J. A Pliocene Fauna from Western Nebraska. Bull. Am. Mus. Nat. Hist., vol. 26, p. 390, 1909.

42 Merriam, J. C. Tertiary Vertebrate Faunas of the North Coalinga Region of California. T. A. P. S., vol. 12, pt. 3, p. 12, 1915.

The better preserved root of the lighter canine (no. 23440, fig. 65) and the relative narrowness account for its much longer appearance. Beyond the difference in size of cross-section the form of the tooth and the manner of wear of the posterior surface point to its being identical with the species represented by the larger canine.



64 65

Figs. 64 and 65. *Platygonus?*, sp. Lower canine teeth, × 1. Fig. 64, no. 23439; fig. 65, no. 23440. Eden beds, California.

Comparisons.—The canines are apparently too large to be referred to the material here described under *Prosthennops edensis.* The specimens are larger and longer than the canine associated with the *Prosthennops*-like teeth from the Thousand Creek, the same measuring but 27 mm. on the outer curve from tip to alveolus. The two canines are believed to be too elongate for reference to any of the forms which have been associated under the genera *Prosthennops* or *Mylohyus.* The heavier tooth might well represent such a canine as that described by Professor Cope under *Platygonus bicalcaratus.*[43] The

[43] Cope, Edw. D. A Preliminary Report on the Vertebrate Palaeontology of the Llano Estacado. 4th Ann. Rept., Texas Geol. Surv., pp. 68–70, 1893.

same author mentions *Platygonus compressus* as being less robust. The corresponding teeth of *Platygonus texanus* Gidley[44] are unknown, though the broken alveoli suggest larger canines than those indicated by the alveoli of the describer's accompanying figure of the skull of *P. vetus* Leidy. The alveolar measurements of *P. vetus* equal the measurements of the present specimens; but the measurements of *P. vetus* are taken from the figure and perhaps through the usual shrinking away of alveolar edges indicate too great a size.

The canines are much longer and heavier than those of the living forms, excepting perhaps *P. labiatus*, the upper canines of which by Dr. Leidy's measurements (16.7 × 14.4 mm.) are fully as heavy as the Eden specimens.[45]

MEASUREMENTS

	Specimen no. 23439	Specimen no. 23440
Total length in straight line	*a*84 mm.	94.5 mm.
Length from alveolar border	51	50
Total length along front curve	94.5	116
Length from alveolar border	55.5	55
Anteroposterior diameter at alveolar border	16.5	14.2
Transverse diameter	12.4	11

a, approximate.

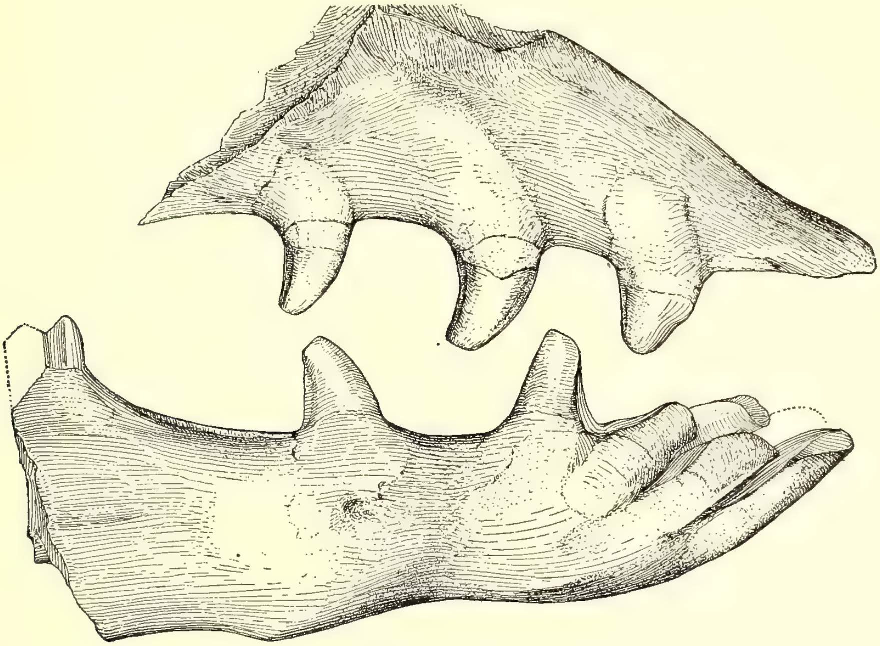
CAMELIDAE

Camels evidently occupied a very important place in the Eden fauna, the discovered remains indicating species of great range of form and size. More ample material may confirm the suggested presence of characters of new generic rank in one or more of the species, which apparently lie in the gap between *Pliauchenia* and *Camelus* rather than within either genus, as at present defined.

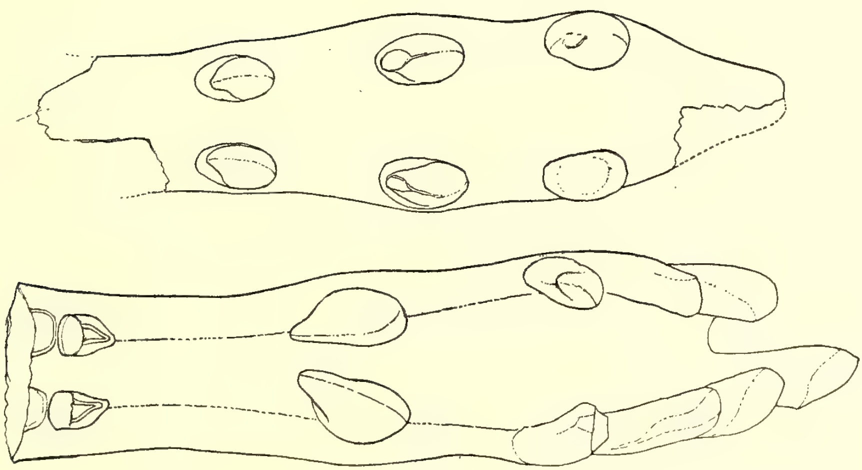
The Eden specimens, so far as observable (note figs. 66, 74–83) differ in the dentition from both *Auchenia* and *Camelops* by the retention of the first premolar. By the apparent absence of the second premolar the specimens differ from the Miocene genus *Procamelus* and agree with *Pliauchenia* of the Pliocene. It has seemed expedient instead of referring all the material to the latter group, to recognize the very marked size characters exhibited by the specimens

[44] Gidley, J. W. On Two Species of Platygonus from the Pliocene of Texas. Bull. Am. Mus. Nat. Hist., vol. 19, pp. 479, 1903.

[45] Leidy, Joseph. The Extinct Mammalian Fauna of Dakota and Nebraska. . . . Synopsis of the Mammalian Remains of North America. Jour. Acad. Nat. Sci. Phila., (2), vol. VII, p. 387, 1869.



66a



66b

Figs. 66*a* and 66*b*. *Pliauchenia merriami*, n. sp. Type specimen, no. 23483, anterior portions of upper and lower jaws, × ½. Fig. 66*a*, lateral view; fig. 66*b*, crown view. Eden beds, California.

(see scale drawings of limb elements), and to separate the light, gazelle-like forms from the heavy and more typically *Pliauchenia*-like species. The former are here tentatively placed under *Procamelus,* originally described by Dr. Leidy from the Loup Fork of Nebraska, and the heavier material under the genus *Pliauchenia* Cope.

PLIAUCHENIA-LIKE SPECIES

This group, as seen in specimens of the gigantic limbs and phalanges, includes at least two distinct forms, one of which is also represented by associated teeth.

1. A new species, *Pliauchenia merriami,* based on the anterior portion of the upper and lower jaws and on associated limb and foot elements of large size, taken from one nodular deposit; also represented by certain tentatively referred material.

2. A similar species, *Pliauchenia,* species A, which is represented by the phalanges and limb fragments of a single camel from a second nodular deposit.

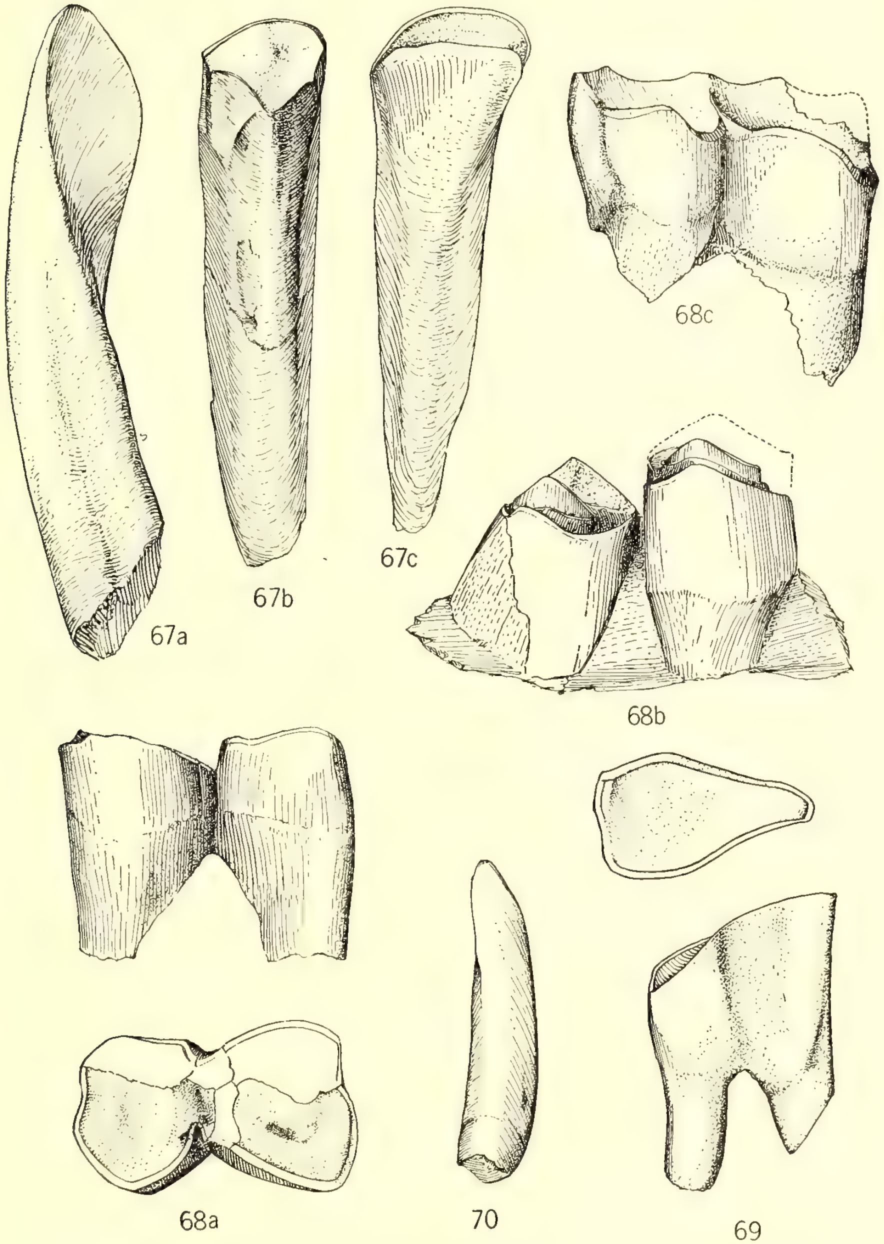
PLIAUCHENIA MERRIAMI, n. sp.

Type.—The upper and lower jaws anterior to the cheek series; complete phalanges of fore and hind feet; portions of metapodials, carpus, and tarsus; sections of radius, humerus, tibia, etc. The jaws and limbs were intimately associated and without doubt belonged to one individual. Univ. Calif. Coll. Vert. Pal. no. 23483 (pl. 47, figs. 1, 2, pl. 48, fig. 11, and figs. 66*a*, 66*b*, 71*a*–71*c*, 92*a*, 93*a*, 94*c*), Univ. Calif. loc. 3270.

Referred material.—Three molar teeth, nos. 23789, 23433, 23435 (figs. 68*a*–68*c*); an upper premolar, no. 23416 (fig. 69); three incisors, nos. 23790, 23783, 23791 (figs. 67*a*–67*c*), and a canine, no. 23792 (fig. 70); portions of metapodials, carpus, and tarsus, and other fragments of a slightly larger individual, no. 23484 (figs. 72*a*–72*b*); and an unciform, no. 23492 (pl. 47, fig. 4). All specimens Univ. Calif. Coll. Vert. Pal.; all from Univ. Calif. loc. 3269.

Characters.—Large size, the elongation of the anterior portion of the jaw and length of posterior diastema, the marked development of the three upper and two lower caniniform teeth as compared to the outer incisor of the lower jaw, and the close juxtaposition of this to the peculiarly shaped canine.

Detailed description.—The jaws (figs. 66*a*–66*b*) are somewhat distorted through lateral compression, the right alveolar border of the upper ramus extending beyond the summits of the teeth of the left side. The premaxillary terminates in the usual camelid beak-like



Figs. 67*a*–67*c*, 68*a*–68*c*, 69, 70. *Pliauchenia merriami*, n. sp. Parts of dentition, × 1. Figs. 67*a*, 67*b*, 67*c*, incisors, nos. 23790, 23783, and 23791; figs. 68*a*, 68*b*, and 68*c*, three molars, nos. 23789, 23433, and 23435; fig. 69, upper premolar, no. 23416, outer and occlusal views; fig. 70, canine, no. 23792. Eden beds, California.

projection. The presence of a shallow maxillary fossa is indicated by a slight indentation above the canine. The lower jaw is more elongate and is also apparently heavier and less constricted in the region just anterior to the cheek teeth than is the usual case in the camels. Mental foramina occur below the posterior border of the first premolar, and the symphysis extends slightly posterior to the same.

Upper jaw.—Incisors one and two are absent, though the former position of I^2 is suggested by a slight swelling of the alveolar border. The three anterior teeth are all large, strongly recurved, and caniniform. They are separated from each other and the cheek tooth series by progressively lengthening diastemata, which are deeply arched. The caniniform incisor is exceedingly stout, equalling the canine at the alveolus in anteroposterior diameter. The tooth, however, has been considerably ground down through attrition with the inferior canine and with the first incisor, which has worn a groove deep into its anterior surface. The canine is long, stout, and furnished with sharply compressed anterior and posterior cutting edges. The first premolar is but little lighter than the canine and closely resembles it in form.

Lower jaw.—The incisors are strong and spatulate, increasing in size from the transversely compressed outer to the heavy, elongated inner incisor. The posterior edge of the third incisor has been flattened through contact with the upper canine. A large, suberect canine directly adjoins the incisor series; its anterior half has been ground away by the superior caniniform tooth, leaving the semblance of a slight diastema. The lower canine is less curved than the upper tooth. The first premolar is somewhat compressed, with remarkably sharp cutting edges, and is strongly recurved and caniniform. In anteroposterior alveolar diameter this tooth equals the preceding. The remnant of the first unit of the lower cheek series, in the form of anterior lobe and alveolus, indicate a narrow but well developed, two-lobed, and double rooted tooth.

Position.—As the present grouping of the camels is so considerably based on the reduction or the retention of the premolars, the proper interpretation of the jaws and the phylogenetic relationship of the species in question rests largely on the correct interpretation of the remnant of this first cheek tooth. The specimen is evidently a premolar, being compressed rather than quadriform. The tooth, however could not represent the double rooted, unreduced $P_{\overline{2}}$ of the genus

Alticamelus.[46] Though the general appearance of the anterior teeth is somewhat similar to that of *A. procerus,* the teeth are markedly heavier, the mandible is proportionately more elongate, and the relative length of the posterior diastema suggests the loss of possibly both $P_{\overline{2}}$ and $P_{\overline{3}}$. The general characteristics of the forms are too far apart (see below) to attempt to refer the tooth remnant to $P_{\overline{4}}$ of either the genus *Camelops* or the genus *Auchenia.* On the one hand, the specimen might represent $P_{\overline{4}}$ of *Pliauchenia;* the proportions are apparently not unlike those of the comparatively small $P_{\overline{4}}$ of *P. spatula* Cope[47] from the Blanco, or even more like the less reduced $P_{\overline{3}}$ of Dr. Matthew's *P. gigas* of the Snake Creek. On the other hand, it well agrees with the form of $P_{\overline{4}}$ of the genus *Camelus,* such as seen in the smaller *C. americanus,* both teeth being bilobed, double fanged, and of proportionate width and height of crown. That the tooth might represent *Camelus* is further suggested by the presence in the collection of a large, triangular shaped, upper premolar (no. 23416, fig. 69) somewhat resembling $P^{\underline{4}}$ of *C. bactrianus.* The transverse thickness of the posterior portion of this premolar exceeds that of the *C. bactrianus* tooth; the anterior portions of the two are both sharply triangular.

In conclusion, it would thus seem that the remnant of the first cheek tooth might very possibly represent either a $P_{\overline{4}}$ of a form resembling the genus *Camelus,* or $P_{\overline{3}}$ of some *Pliauchenia*-like species.

COMPARATIVE MEASUREMENTS OF THE TEETH

	Pliauchenia? merriami, Type, no. 23483	Camelus dromedarius, Univ. Calif. Coll. Vert. Pal. 22843
$I^{\underline{3}}$, anteroposterior diameter	19.7 mm.	
$I^{\underline{3}}$, transverse diameter	13	
C, anteroposterior diameter	20	20 mm.
C, transverse diameter	12.9	16.5
$P^{\underline{1}}$, anteroposterior diameter	15.2	13.5
$P^{\underline{1}}$, transverse diameter	9	10
$I_{\overline{3}}$, anteroposterior diameter	20	16.5
$I_{\overline{3}}$, transverse diameter	10.5	12
Length of diastema anterior to canine	23	
Length of diastema posterior to canine	30	20

[46] Matthew, W. D., and Cook, H. J. A Pliocene Fauna from Western Nebraska. Bull. Am. Mus. Nat. Hist., vol. 26, pp. 403–406, figs. 19, 20, 1909.

[47] Cope, Edw. D. A Preliminary Report on the Vertebrate Palaeontology of the Llano Estacado. 4th Ann. Rept. Texas Geol. Surv., pp. 70–73, pl. 21, figs. 1, 2 (1892), 1893.

COMPARATIVE MEASUREMENTS OF THE TEETH—(*Continued*)

	Pliauchenia? merriami, Type, no. 23483	Camelus dromederias
Length of diastema posterior to C	28 mm.	16 mm.
Length of diastema posterior to P^1	37+	44
C, upper, anteroposterior diameter	23	27
C, lower, transverse diameter	*a*14	20.5
$P_{\bar{1}}$, anteroposterior diameter	20.7	16
$P_{\bar{1}}$, transverse diameter	10.5	12
Length of diastema anterior to canine	absent	10
Length of diastema posterior to canine	33	26
Length of diastema posterior to $P_{\bar{1}}$	55	66

a, approximate.

General comparison.—The specimen agrees with *Procamelus* and more recent forms in the loss of the first and second upper incisors. It is decidedly larger than any of the types described under *Procamelus* and differs from these forms in the evident reduction of its premolars.

Except in size the specimen bears little resemblance to *Alticamelus* as seen in *A. procerus* of the Snake Creek. The lower jaw is noticeably elongate anterior to the cheek tooth series when compared to the figures of the relatively short-proportioned jaw of *A. procerus* and *A. giraffinus.*[48] Both upper and lower teeth are considerably more developed than in these forms, Dr. Matthew stating that the lower teeth of *A. giraffinus* are even smaller than those of the living camel and indistinguishable from those described by Dr. Leidy as *Procamelus robustus.* A comparison of the length of the limb elements points to the Eden form being larger than *A. procerus.* Data on the corresponding elements of *A. giraffinus* are unavailable. It is, however, evident that the specimen cannot be referred to the genus *Alticamelus.*

The fossil differs very markedly from *Camelops,* as seen in the Rancho La Brea *C. hesternus,*[49] in the following characters: (1) the lack of an actual diastema between the outer incisor and canine of the lower jaw, *versus* the broad diastema figured in the type specimen of the Rancho La Brea form of *Camelops hesternus.* (The presence or absence of this diastema may possibly be somewhat dependent on age, as it is reduced in other specimens of the Rancho La Brea form); (2) the enlarged first premolar in both jaws *versus* its total absence; (3) the considerably larger size and much greater strength and

[48] Matthew, Wm. D. Mem. Am. Mus. Nat. Hist., vol. 1, 1901.

[49] Merriam, John C. The Skull and Dentition of a Camel from the Pleistocene of Rancho La Brea. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 305–323, 1913.

development of all teeth anterior to the premolar series; (4) the bilobed, double fanged, first tooth of the cheek tooth series *versus* a greatly reduced tooth in *C. hesternus* ($P_{\overline{3}}$ usually absent); (5) the relatively large size of the outer incisor of the lower jaw *versus* the first incisor as seen in *C. hesternus.*

The dental arrangement of the lower jaw is very similar to that occurring in *Pliauchenia spatula,* as figured by Cope, in the relative proportions of the posterior diastemata, the position of the mental foramen, in the absence of a well defined diastema between the canine and outer incisor, and in the proportions of the first cheek tooth. The specimen, however, differs from Professor Copes type in its much greater size and the accompanying marked development of its first incisors and first premolars. The elongated muzzle, with its strongly developed caniniform premolars in both the upper and lower jaw, would scarcely seem to come within the limits of (*Pliauchenia*) *Megatylopus* as defined by Dr. Matthew (*op. cit.,* p. 396): "The second premolar absent in both jaws, the first retarded or absent . . . the diastema behind $P^{\underline{1}}$ is rather short, and a much shorter diastema intervenes between $P^{\underline{1}}$ and the canine alveolus. This, with the general proportions of the face indicates a much shorter muzzle than in *P. spatula.*" The anterior portion of the upper jaw of *Megatylops gigas* is unfortunately unknown. The caniniform premolar of the specimen is apparently much more robust than the corresponding tooth of *M. gigas* that is described as "a good sized tooth, with pointed spatulate crown, but which appears retarded in development." Lower jaws referred by Dr. Matthew to *M. gigas* are said to show the absence of $P_{\overline{2}}$, but $P_{\overline{3}}$, and $P_{\overline{4}}$ less reduced than in *P. spatula.*

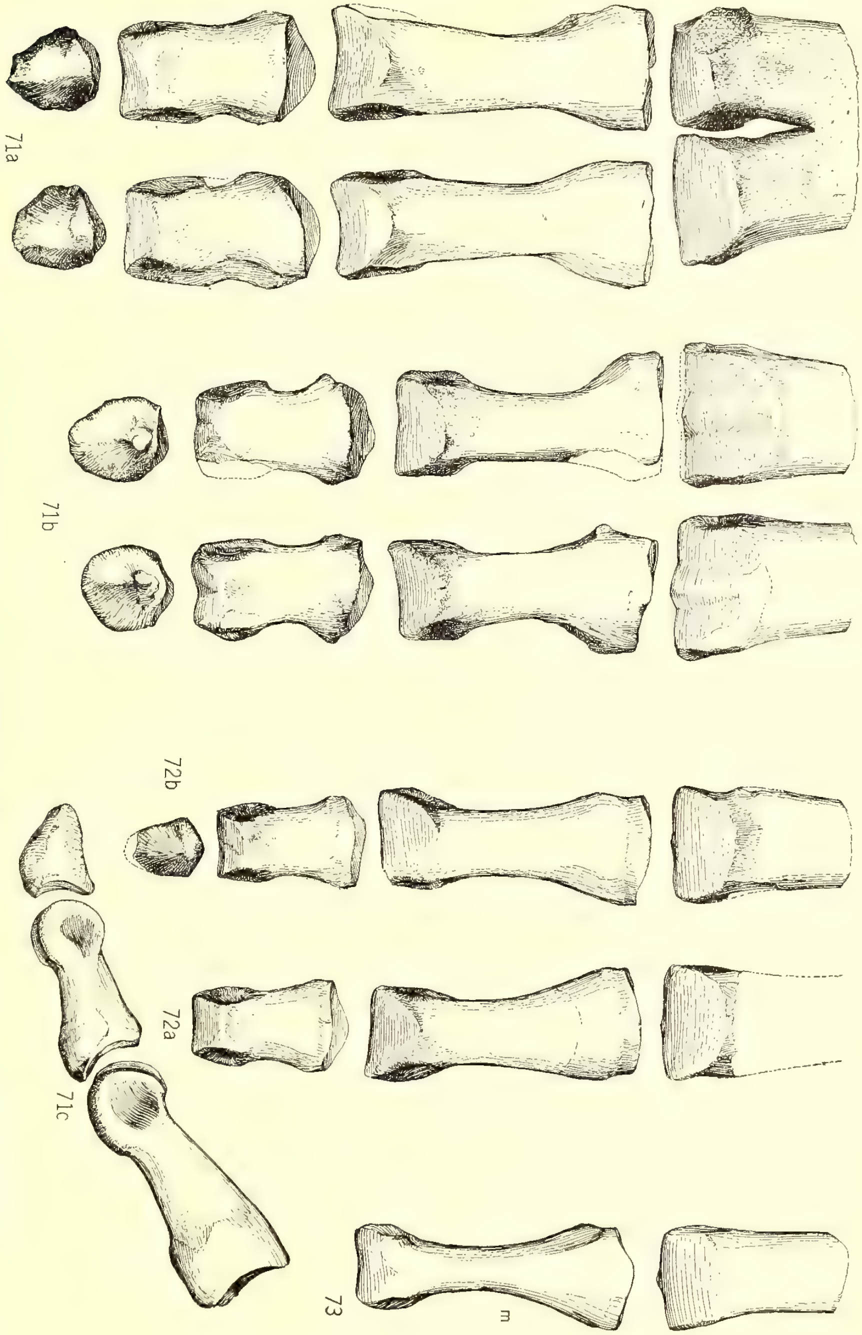
As suggested above, the remnant of the first cheek tooth might represent such a $P_{\overline{4}}$ as that of *Camelus,* the fossil considerably resembling this genus in general character. The specimen, however, differs from the *Camelus americanus,*[50] based on a lower jaw from the Hay's Spring Pleistocene, in the strength of the lower canine, which is weakly incisiform in *C. americanus,* and in the much greater general size, the present specimen measuring 150 mm. from incisive border to cheek tooth series *versus* 114 mm. in *C. americanus.* The lower canine of *Camelus sivalensis* of the late Indian Pliocene is well developed and unseparated from the incisors, somewhat as in the present specimen,

[50] Wortman, Jacob L. The Extinct Camelidae of North America and Some Associated Forms. Bull. Am. Mus. Nat. Hist., vol. 10, pp. 133–134, 1898.

but the first premolar is small, and the form is evidently of different proportions. Compared to *C. dromedarius* the maxillary-premaxillary portions of the fossil are seen to be proportionately more elongate than in the living species, the first upper and lower premolars are much heavier than the lower canine, and the outer incisors are more robust.

In *résumé,* the dentition of the new specimen cannot be referred to the genera *Alticamelus, Auchenia,* or *Camelops.* The general dental formula and arrangement in front of the cheek tooth series suggests *Pliauchenia* or *Camelus,* but in their development the anterior teeth differ from those of both genera. The specimen represents a giant specialized form that might have been derived from ancestral stock resembling *Pliauchenia spatula.*

Limb elements.—The scaphoid and lunar are broader transversely, deeper anteroposteriorly and narrower dorsoventrally than the corresponding bones of *Camelops,* giving the broad and flattened carpus increased strength. The tarsus (pl. 47 and fig. 2) differs more from the Rancho La Brea type than does the carpus, the cuboid being broader transversely and much shallower dorsoventrally, while the navicular is both broader transversely and deeper dorsoventrally. The general form of the cuboid is, however, nearer that of *Camelops* than that of the llama, the calcaneal groove of the anterodorsal surface and the deep gutter diagonally crossing the outer side being deep and prominent, instead of relatively inconspicuous as in the llama. The foot bones are well represented (figs. 71*a*–71*c*). The writer has referred the longer phalanges of *Pliauchenia merriami* to the manus and the shorter to the pes, as in the genus *Camelops.* In *Auchenia* the bones of the manus are slightly heavier and shorter than those of the pes, but this form has been seen to be farther removed from the Eden type than is the Rancho La Brea. The accompanying table shows comparative measurements of the foot of the large Eden forms with those of *Camelops hesternus, Pliauchenia gigas,* and *Alticamelus procerus.* The first phalanx of the manus in the present form exceeds in length that of the large *Pliauchenia* of the Snake Creek, while it is of equal length with *Camelops,* in which the pes is, however, longer.



Figs. 71*a*–71*c*, 72*a*–72*b*, 73. Camel foot bones, × ⅓. Figs. 71*a*–71*c*, *Pliauchenia merriami*, n. sp., distal ends of metapodials with phalanges, no. 23483. Figs. 72*a*, 72*b*, *Pliauchenia*, sp. A, ends of metapodials with phalanges, no. 23484; fig. 73, *Procamelus*-like sp., metapodial and first phalanx, nos. 23391, 23392. Eden beds, California.

COMPARATIVE FOOT MEASUREMENTS

	Pliauchenia merriami, n. sp. No. 23483		No. 23484 Subform A		Procamelus, n. sp. no. 23392	Camelops hesternus	
	Fore foot	Hind foot	Foot (?)			Fore foot	Hind foot
Length of phalanx 1	130 mm.	107 mm.	110 mm.	*a*110 mm.	113 mm.	133 mm.	119 mm.
Diameter of proximal end of phalanx 1....	49	48	46	45	40	47.5	48.5
Least diameter of shaft of phalanx 1	29	32	27.5	27.5	18		
Length of phalanx 2	78	72	64	60		60	56.5
Diameter of proximal end of phalanx 2....	46	42	36	36		34.5	38
Length of phalanx 3	36	36	25				
Dorsoventral diameter of phalanx 3	37	*a*36	20.5				
Diameter of greatest metapodial trochlea	52		45			51	
	Pliauchenia gigas Matthew		Alticamelus procerus Matthew				
Length of phalanx 1	128		108	98			
Diameter of proximal end of phalanx 1....	52		36	33			

a, approximate.

b, difference due to crushing?

PLIAUCHENIA, sp. A

Material.—Phalanges of the fore and hind feet, carpus and portions of metapodials, radius, humerus, etc., of type individual, Univ. Calif. Coll. Vert. Pal. no. 23484 (pl. 47, fig. 5; pl. 48, fig. 10, text figs. 72, 92*b*–92*c*), and a referred radius, Univ. Calif. Coll. Vert. Pal. no. 23486 (pl. 47, fig. 3).

Description.—The specimen indicates the presence of a species somewhat smaller than *P. merriami*, and of markedly different proportions, as shown by the scale drawings of the radius and humerus joint (pl. 48, figs. 10, 11), of the trochlea (fig. 92*c*), of the carpus (pl. 47, fig. 5), and of the phalanges (fig. 72). The distal portion of the referred complete radius (no. 23486, pl. 47, fig. 3) is of the same size as that of a radial section associated in the nodular remains of the above specimen. The bone is nearly as long as that of the modern dromedary (510 mm. *versus* 580 mm., Univ. Calif. Coll. Vert. Pal. specimen 22843). It is much larger than in *Procamelus robustus* (averaging in length 379 mm. to 464 mm.), and is shorter than a radius referred to *Pliauchenia gigas* (measuring 759 mm.).

PROCAMELUS-LIKE SPECIES

This group embraces three or more small camelid forms, represented by numerous jaw and tooth fragments and the unassociated portions of limbs. A reference of limbs to dentition has seemed impracticable, beyond calling attention to the fact that teeth and limbs individually evidence the occurrence in the Eden of at least three well defined species of small camels: (1) A new species, *Procamelus edensis edensis,* and new sub-species, *Procamelus edensis raki,* based on portions of several series of lower cheek teeth; (2) a new species, *Procamelus,* species A, based on the portion of a mandible; (3) two or more indeterminate species, partially or wholly referrable to the above: (*a*) forms represented by maxillary and premaxillary material; (b) forms represented by stout *Procamelus*-like limb material; (*c* and *d*) forms represented by light *Procamelus*-like limb fragments. Should more ample material prove the second premolars of these small forms to be generally missing, this group might be more correctly referred to *Pliauchenia* than to *Procamelus.*

PROCAMELUS(?) EDENSIS EDENSIS, n. sp. and n. subsp.

Type.—The right ramus of a mandible containing portions of the cheek tooth series, the remaining dentition indicated by alveoli, Univ. Calif. Coll. Vert. Pal. 23428 (figs. 74 and 81), Univ. Calif. loc. 3269.

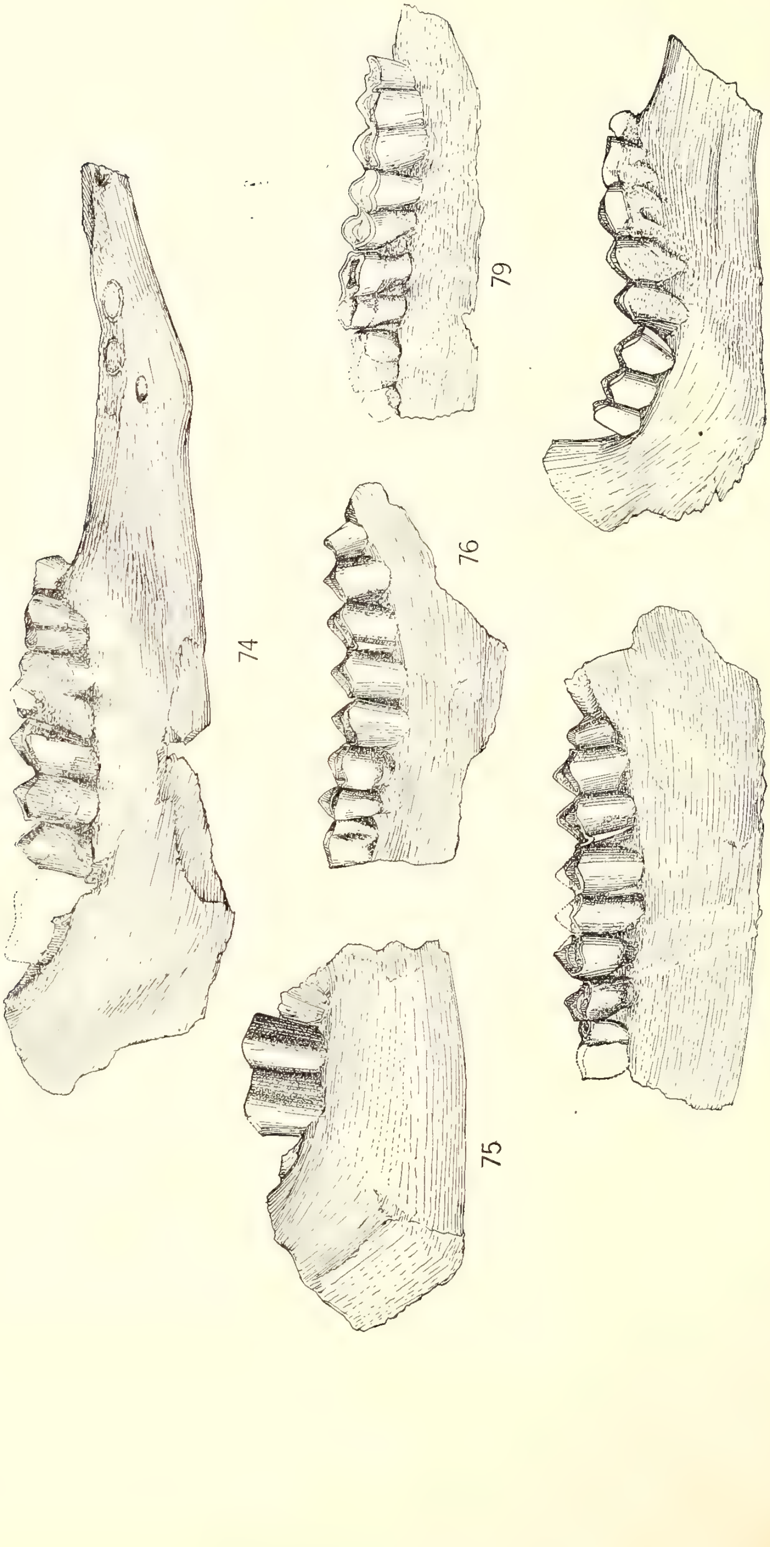
Referred material.—A slightly larger form from the same locality, represented by the posterior portion of the right mandible containing portions of $M_{\overline{2}}$ and $M_{\overline{3}}$, Univ. Calif. Coll. Vert. Pal. no. 6728 (fig. 75).

Characters (*Generic*).—The loss of $P_{\overline{2}}$ and the reduction of $P_{\overline{3}}$, thus differing from *Procamelus.* The anterior position of the apparently caniniform first premolar with the position of the canine alveolus in close proximity to that of the first premolar, and the resulting long diastema anterior to the cheek series; the proportionately high crowns of the molars, as well as the length of the worn series in comparison to that of worn series in the smaller Eden camels. The strength of the mandibular symphysis.

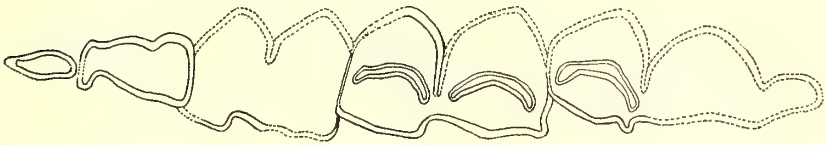
MEASUREMENTS[51]

	Type specimen Univ. Calif. Coll. Vert. Pal. 23428
Length, $P_{\overline{3}}$ to $M_{\overline{3}}$ inclusive	107 mm.
Length of molar series	85.5
Length of diastema posterior to $P_{\overline{1}}$	51
Length of diastema posterior to C	2

[51] For more complete measurements see comparisons, page 371.



Figs. 74 to 79. *Procamelus*, lower jaw specimens, × ½. Fig. 74, *P. e. edensis*, n. sp., type specimen, no. 23428; fig. 75, *P. e. edensis*, n. sp., referred posterior portion of mandible with M_3, no. 6728; fig. 76, *P. e. raki*, n. subsp., fragment of mandible with lower teeth, no. 23423, type specimen; fig. 77, *P. e. raki*, n. subsp., a larger referred mandible, no. 23427; fig. 78, *P. e. raki*, n. subsp., referred mandible with portions of cheek tooth series, no. 1050; fig. 79, *P. e. raki*, n. subsp., referred fragment of mandible with cheek tooth series compiled from two specimens, no. 23771. Eden beds, California.



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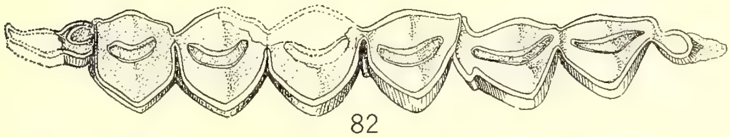

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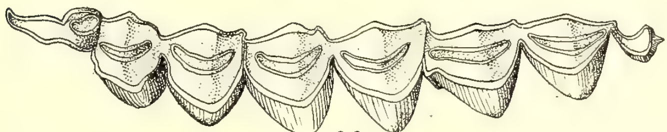

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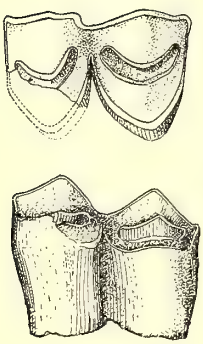
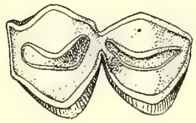
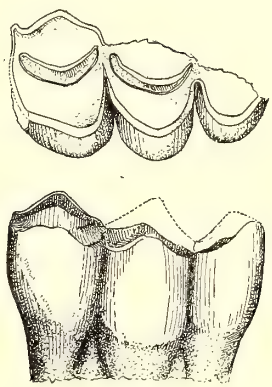




84a



84b

84c

Figs. 81 to 84*c*. *Procamelus,* lower cheek teeth, × 1. Fig. 81, *P. e. edensis,* n. sp., occlusal view of type specimen, no. 23428 (see fig. 74); fig. 82, *P. e. raki,* n. subsp., lower teeth, no. 23427 (see fig. 77); fig. 83, *P. e. raki,* n. subsp., occlusal view of type specimen, no. 23423 (see fig. 76); figs. 84*a* to 84*c*, Camelid, three molar teeth, nos. 23436, 23438, and 23438A. Eden beds, California.

Description.—The teeth (figs. 74 and 81) are considerably worn, and, perhaps, as a character due to age, have the appearance of being moved diagonally forward, the inner, posterior edge of one molar projecting beyond the corresponding anterior edge of the next posterior tooth. The crowns are comparatively short and broad. The heel and central lobe of the relatively large third molar are broken. The presence of the usual camelid buttress is suggested at the anterior external corner of the last molar by the remnant of a fold in the broken enamel. The last premolar is a well developed tooth, the form indicating the presence of double crescents in the less worn state. Premolar three is small and double rooted. The smooth, knife-like sulcus points to the total absence of the second premolar. The anterior lateral portion of the mandible, which is somewhat broken away, exhibits two caniniform alveoli lying end to end. The usual posterior inclination of the first premolar, however, may have resulted in a slight diastema occurring between it and the canine in the unbroken edge. The second incisor is also represented by the alveolus. A mental foramen is situated below the posterior edge of the first premolar.

Description of referred specimen.—No. 6728 (fig. 75) consists of the posterior portion of a right mandible with portions of the last molar and the alveolus of $M_{\overline{2}}$. The two lobes remaining of $M_{\overline{3}}$ are similar in size to the type specimen (no. 23428). No suggestion exists of the usual camelid buttress that is distinctly suggested in the type specimen.

PROCAMELUS(?) EDENSIS RAKI, n. sp.

Type.—A premolar-molar series from the left side of the lower jaw, Univ. Calif. Coll. Vert. Pal. no. 23423 (figs. 76, 83), Univ. Calif. loc. 3269.

Referred material.—A second and slightly larger cheek tooth series, contained in the portion of a mandible from the left side, no. 23427 (figs. 77, 82); a third series 1050 (fig. 78), from the right side; portions of two series, no. 23771 (fig. 79), from the left side of the jaw; three lower molars, nos, 23436, 23438, and 23438A (figs. 84*a*–84*c*). All specimens in Univ. Calif. Coll. Vert. Pal., and from Univ. Calif. loc. 3269.

Characters.—The general small size of the teeth, together with the narrowness of $P_{\overline{4}}$; the relatively short anteroposterior length of the series; and the presence of a marked, inwardly sloping buttress at the anteroexternal angle of $M_{\overline{3}}$.

MEASUREMENTS OF THE TYPE AND REFERRED SPECIMENS OF PROCAMELUS EDENSIS EDENSIS, N. SP., AND P. EDENSIS RAKI, N. SUBSP.

	Procamelus edensis edensis n. sp.	Procamelus edensis raki, n. sp.				
	No. 23428	No. 23423	No. 23427	No. 23771	No. 24029	No. 1050
	Type	Type				
Greatest length, $P_{\overline{3}}$ to $M_{\overline{3}}$, inclusive	107 mm.		86 mm.			85.5 mm.
Greatest length, $M_{\overline{1}}$ to $M_{\overline{2}}$, inclusive	85.5		75	82.5 mm.	68.5 mm.	67
$P_{\overline{3}}$, greatest anteroposterior diameter	10.8	10.5 mm.				
$P_{\overline{3}}$, greatest transverse diameter	6.6	7				7
$P_{\overline{4}}$, greatest anteroposterior diameter	15	11.2	13		14.8	12.8
$P_{\overline{4}}$, greatest transverse diameter	9	9.6	7.3	7.8	(7.5)	
$M_{\overline{1}}$, greatest anteroposterior diameter	20.6	18.7	20	20.8	21.5	17
$M_{\overline{1}}$, greatest transverse diameter		14.2	14	13.1	12.5	
$M_{\overline{2}}$, greatest anteroposterior diameter	26.5		20.8	28	21	22.2
$M_{\overline{2}}$, greatest transverse diameter	16		14	14.5	14	
$M_{\overline{3}}$, greatest anteroposterior diameter	37.4		32.8	33.5	21.5	30
$M_{\overline{3}}$, greatest transverse diameter	16.2		12.2	14.5	14	

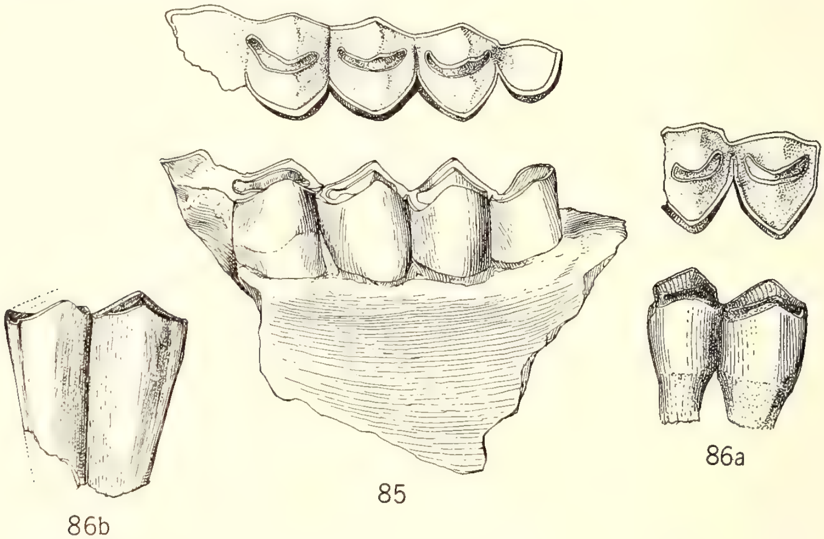
Description.—The teeth (figs. 76 and 83) are moderately long-crowned, and the exterior faces somewhat rugose. The crowns of the main lobes of the $M_{\overline{3}}$ are wide anteroposteriorly and narrow transversely. Toward the root the teeth, as is usual in the camels, become relatively shorter anteroposteriorly and thicker transversely, the resulting relative transverse breadth of worn teeth being well illustrated throughout the series and shown in figure 88 of a single tooth. The heel of the last molar, small and hooked in the type specimen, varies in form and size in different individuals, being quite large in several. The $M_{\overline{2}}$ is heavier than the $M_{\overline{3}}$. The first molar is shorter crowned than the other two, tending to be brachyodont. The last premolar is double rooted, and is narrowly triangular in cross-section, its anteroposterior diameter equalling 73% of that of the first molar. The styles of the teeth are strongly developed. A referred specimen, no. 1050 (fig. 78), with all units of the cheek tooth series represented though somewhat broken, illustrates the very small size of $P_{\overline{3}}$. Another referred specimen, no. 23771 (fig. 79), shows just anterior to the double rooted $P_{\overline{4}}$ the small, round alveolus of the posterior root of $P_{\overline{3}}$, and further illustrates the presence of the small, third premolar in this species.

PROCAMELUS(?), sp. A, *cervid-like* dentition

Type.—The posterior portion of a left mandible containing $M_{\bar{3}}$ and a portion of $M_{\bar{2}}$, Univ. Calif. Coll. Vert. Pal. no. 23426 (fig. 85), Univ. Calif. loc. 3269.

Referred material.—Univ. Calif. Coll. Vert. Pal. no. 23437 and no. 23437A (figs. 86*a*, 86*b*), Univ. Calif. loc. 3269.

Characters.—The low crowns and unusual transverse breadth of the teeth; the markedly even plane of the inner tooth faces; and the peculiar, fine horizontal graining of the enamel.



Figs. 85 to 86*b*. *Procamelus*, sp. A. Cervid-like type of dentition. Fig. 85, posterior portion of mandible with $M_{\bar{2}}$ and $M_{\bar{3}}$, no. 23426, outer and occlusal views, × 1; fig. 86*a*, molar tooth, no. 23437, × 1; fig. 86*b*, molar tooth, no. 23437A, × 1; Eden beds, California.

Measurements of Procamelus?, sp. A—Referred Teeth

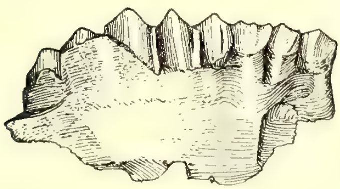
	No. 23426
$M_{\bar{2}}$, anteroposterior diameter	21.8 mm.
$M_{\bar{2}}$, transverse diameter	14
$M_{\bar{3}}$, anteroposterior diameter	33
$M_{\bar{3}}$, transverse diameter	13.8

In the evident presence of a buttress at the anteroexternal corner of the last molar, in the large heel, and the general shape of the teeth in cross-section this specimen alone resembles the preceding. The heel has three-fourths of the anteroposterior diameter of the main lobes as in *P. edensis edensis, versus* one-third as in *P. edensis raki.* That the distinctive characters by which this specimen differs from the former specimens are not due to age is evidenced by the general

appearance and the sharpness of the crenulated cusps. The last molar is relatively smaller than that of either of the specimens grouped under *P. edensis* and is markedly broader than that of any of the forms grouped under *P. edensis raki.* The specimen plainly differs also from the former groups in the flat and even plane of its inner tooth faces.

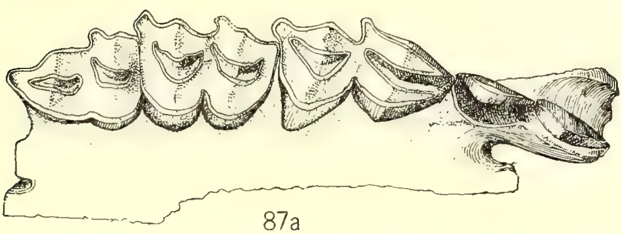
PROCAMELUS?, indet. sp. or subsp.

Material.—Portion of a left maxilla, containing Dp^3, Dp^4, M^1, M^2, Univ. Calif. Coll Vert. Pal. no. 23425 (figs. 87*a*–87*c*); the fragments of a right maxilla with M^1, M^2, Univ. Calif. Coll. Vert. Pal. no. 23434; the anterior portion of a small camel jaw containing the first premolars and the canines, Univ. Calif. Coll. Vert. Pal. no. 23430 (fig. 89), an upper cheek tooth, no. 24031 (fig. 88), and two incisors, no. 1053 (figs. 90*a*–90*b*). All from Univ. Calif. loc. no. 3269.

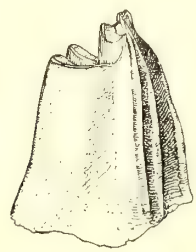


87b

87c



87a



88

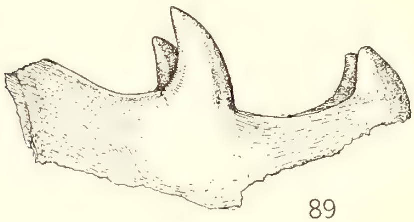
Figs. 87*a* to 88. *Procamelus?,* indet. sp. Upper dentition. Figs. 87*a* to 87*c*, fragment of maxillary with Dp^3, Dp^4, M^1, and M^2, no. 23425; fig. 87*a*, occlusal view, × 1; fig. 87*b*, outer view, × ½; fig. 87*c*, inner view, × ½. Fig. 88, molar, no. 24031, × 1. Eden beds, California.

Measurements

	No. 23425
Length, Dp^3 to M^2	80.6 mm.
Dp^3, anteroposterior diameter	17.8
Dp^4, anteroposterior diameter	18.3
M^1, anteroposterior diameter	23.5

Description.—Specimen no. 23425 (figs. 87*a*–87*c*) shows the anterior corner of the zygoma, the lower edge of the orbit, the infraorbital foramen, and a portion of the palate. The postpalatine foramen lies opposite the anterior edge of Dp^3 *versus* the middle of P^4 as in

Wortman's figure (fig. 20) of *P. gracilis*,[52] and the apex of the suture line between the palatine and maxillary occurs opposite the anterior edge of Dp^4 *versus* that of M^2 as in *P. gracilis*. There is also an interesting suggestion of the maxillary fossa which is present in *Pliauchenia gigas, Alticamelus*,[53] and *Camelops*, but absent in *Auchenia* and *Camelus*. The second molar has not come into use, Dp^3 and Dp^4 still remain in place. M^1 and the deciduous molars are furnished with well developed parastyles and mesostyles, both being much more prominent than in the referred lower teeth. A cingulum crosses the inner extent of the posterior lobe of the first molar near the summit. Dp^4 is quadrate and molariform.



89

90a

90b

Fig. 89 to 90*b*. *Procamelus?*, indet. sp. Fig. 89, anterior portions of premaxillaries with canines and incisors, no. 23430; figs. 90*a*, 90*b*, incisors, no. 1053; × 1. Eden beds, California.

Specimen no. 23434, from the same locality, represents a more mature stage, M^1, M^2 being in place. The teeth are slighly heavier, otherwise similar to those of the preceding specimen.

Measurements of No. 23434

M^1, anteroposterior diameter	23.5 mm.
M^1, transverse diameter	17
M^2, anteroposterior diameter	21
M^2, transverse diameter	19.5

Specimen no. 23430 (fig. 89). The sharp, pointed premolars are recurved and caniniform, and greatly exceed the small canines in size. Long diastemas lie anterior and posterior to the canines, and are arched in the usual manner. The form apparently differs markedly from that described under *Procamelus edensis raki*, type specimen,

[52] Wortman, Jacob L. The Extinct Camelidae of North America and Some Associated Forms. Bull. Am. Mus. Nat. Hist., vol. 10, fig. 20, p. 125, 1898.

[53] Matthew, W. D., and Cook, Harold J. A Pliocene Fauna from Western Nebraska. Bull. Am. Mus. Nat. Hist., vol. 26, pp. 361–414, 1909. Merriam, John C. The Skull and Dentition of a Camel from the Pleistocene of Rancho La Brea. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 305–323, 1913. Scott, W. D. A History of Land Mammals of the Western Hemisphere, p. 398, 1913.

both in the long diastema occurring between the first premolar and the canine, and in the very small size of the canine teeth. No material exists for comparison with the smaller mandibles described above under *P. edensis edensis,* or *Procamelus,* species A, to one of which species the specimen may belong.

MEASUREMENTS

	Indeterminate no. 23430	Procamelus? edensis edensis, n. sp. no. 23428
Length of diastema posterior to $P_{\bar{1}}$	17+ mm.	51 mm.
Anteroposterior diameter $P_{\bar{1}}$ at alveolus	8.3	9.4
Length of diastema anterior to $P_{\bar{1}}$	15	2
Anteroposterior diameter of canine at alveolus	6.5	9.3
$P_{\bar{1}}$, apparent height above alveolus	13	
Apparent height of canine above alveolus	9	

PROCAMELUS? FORMS WITH STOUT LIMBS

Material.—A long slender first phalanx and a referred metapodial trochlea, nos. 23392 and 23391 (fig. 73, also pl. 48, figs. 8*a, c*); the proximal portion of first phalanx, no. 23393 (pl. 48, fig. 8b); the proximal portions of several metapodials, no. 24032 (fig. 93*a*), no. 23493; and seven astragli: no. 23383 (fig. 94*b*), no. 23382 (fig. 94*a*) with associated portion of tibia and tarsal joint; and nos. 22379, 23380, 709, 485, and 821. All specimens in Univ. Cal. Coll. Vert. Pal. All from Univ. Calif. Eden localities.

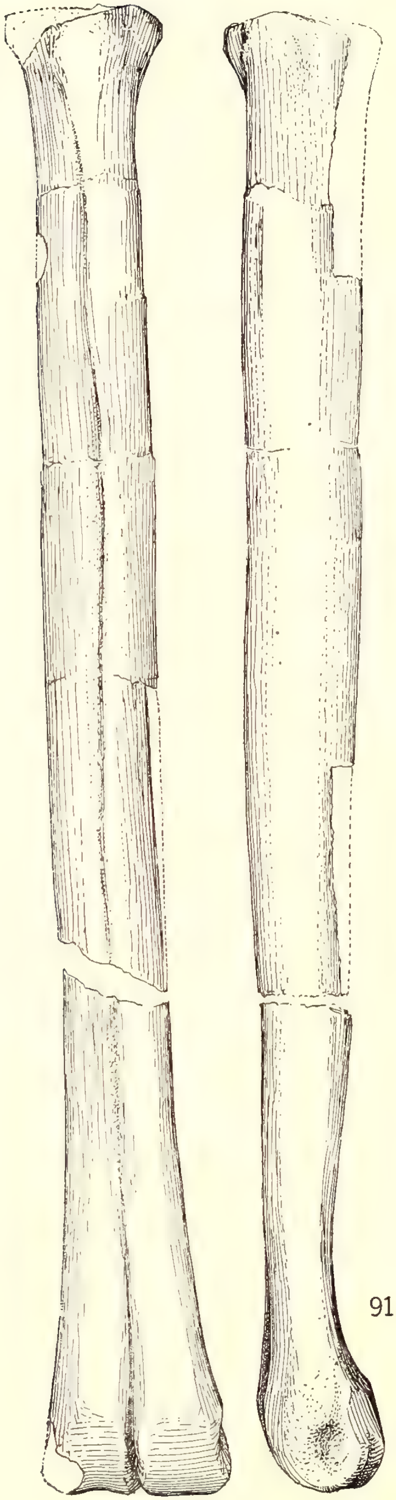
Discussion.—The long, slender phalanx (fig. 73) and other material of this section suggests the presence of a large *Procamelus*-like form or forms. The scale drawings of various limb elements (figs. 71–73, 91–94, pl. 48) indicate the great size difference between the material and that described above under *Pliauchenia* (*?Megatylopus* Matthew).

The phalanx, no. 23391, is fully as long as those of the smaller of the two foregoing *Pliauchenia* specimens, described under *P. merriami,* but is noticeably lighter, the shaft being greatly constricted in its middle region, where it measures but 18 mm., instead of 27 mm. as in species A.

Another first phalanx, represented by the proximal portion, no. 23393 (pl. 48, fig. 8*b*) is somewhat smaller. It may represent the opposite limb or a size variation of the first.

A number of trochleas of equal size, nos. 23486 and 24032 (fig. 92*d*), and the proximal portion of metapodial no. 23493 (fig. 93*a*) agree in general proportions with the foregoing phalanges and may represent the same or similar species.

The representation of more than a single species in the material of this section is indicated in the variation in a fine series of camelid



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astragali. This is marked in the two that are nearest of height, nos. 23382 and 23383 (figs. 94*a* and 94*b*), the first differing from the second in: (1) the transverse narrowness of the dorsal trochlea through thinness of the outer condyle and narrowness of the inner groove; and (2) the prominence of the outer condyle of the ventral trochlea in respect to the inner condyle.

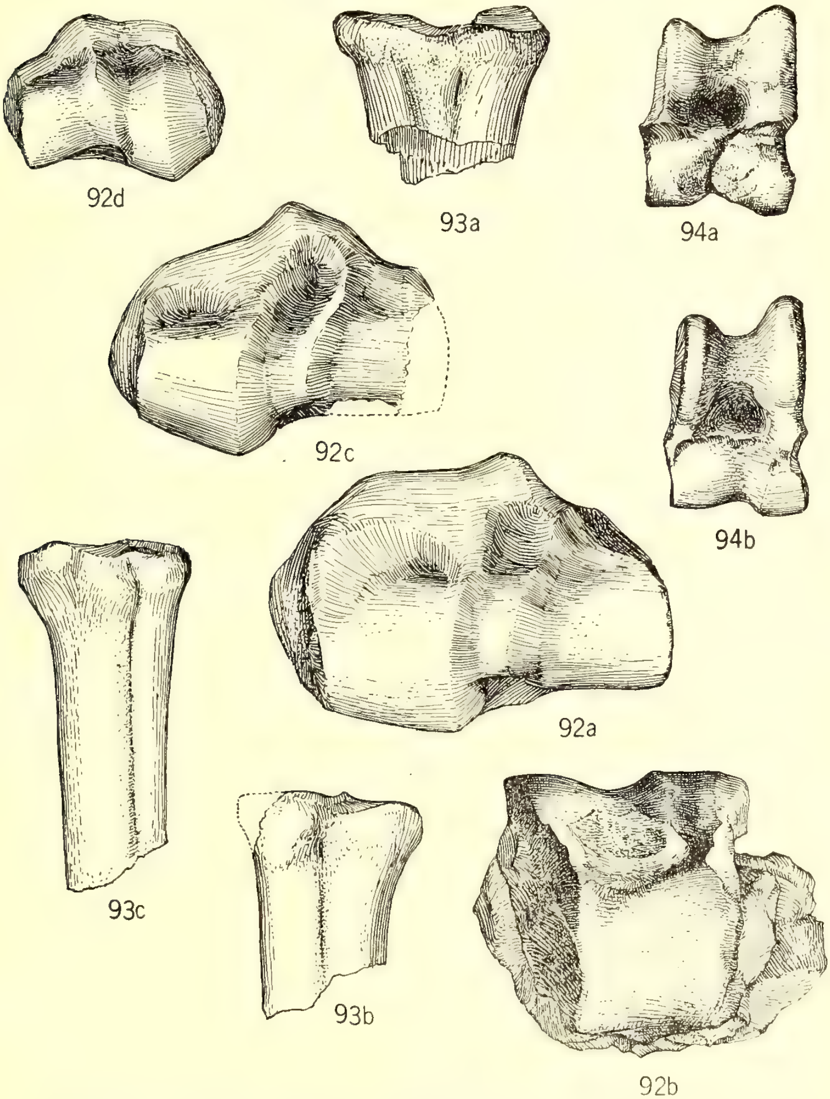
PROCAMELUS(?) FORMS WITH SLENDER LIMBS

Material.—A small second phalanx, no. 23385 (pl. 48, fig. 3); the trochlea of two first phalanges, nos. 23386, 23773 (pl. 48, figs. 5*a*, 5*b*); the proximal portion of two metapodials, nos. 23480 and 23479 (figs. 93*b*, 93*c*); the distal end of a humerus, no. 24284 (fig. 92*d*); an ulna-radial section, no. 23482 (pl. 48, fig. 9); a scaphoid, no. 24035 (pl. 48, fig. 7*a*); and scaphoid no. 23399 (pl. 48, fig. 7*b*). Various localities, all specimens in Univ. Calif. Coll. Vert. Pal.

Discussion.—The trochlea of two slender first phalanges, nos. 23386 and 23773 (pl. 48, figs. 5*a*–5*b*) are considerably heavier than that of phalanx no. 23387 (pl. 48, figs. 2*a*–2*b*) of the following section. The two fragments are believed to represent the moderate sized species further suggested by the other material of this section. Specimen no. 23386 is very similar and but slightly larger than one from the Coalinga Etchegoin (no. 21243) in the Univ. Calif. Coll. Vert. Pal.

Fig. 91. *Procamelus?,* sp. Cannon bone, no. 23422, anterior and lateral views, × ½. Eden beds, California.

A perfect specimen of a small second phalanx, no. 23385 (pl. 48, fig. 3), was found with no. 23387 of the following section. Like the referred fragments of first phalanges and metapodials it is of a considerably stouter form than the specimens of the following section.



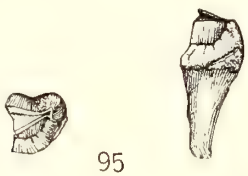
Figs. 92*a*–92*d*, 93*a*–93*c*, 94*a*–94*b*. *Pliauchenia* and *Procamelus*. Limb elements, × ½. Figs. 92*a*, 92*c*–92*d*, distal ends of humerii: fig. 92*a*, *Pliauchenia merriami*, n. sp., no. 23483; fig. 92*c*, sp. A, no. 23484; fig. 92*d*, *Procamelus*, sp., no. 24284. Figs. 93*a*–93*c*, *Procamelus*, sp., proximal ends of metapodials: fig. 93*a*, no. 23493; fig. 93*b*, no. 23480; fig. 93*c*, no. 23479. Figs. 94*a*–94*b*, astragali: fig. 94*a*, *Procamelus*, sp., no. 23382; fig. 94*b*, *Procamelus?*, sp., no. 23383. Fig. 92*b*, *Pliauchenia*, sp. A, no. 23484. Eden beds, California.

PROCAMELUS FORMS WITH VERY SLENDER ELONGATED LIMBS

Type.—An exceedingly long and slender metapodial, Univ. Calif. Coll. Vert. Pal. no. 23422 (fig. 91), loc. 3269.

Referred material.—The distal portion of a small metapodial, no. 23498 (pl. 48, fig. 1); and a fragment of the distal end of a first phalanx, no. 23387 (pl. 48, figs. 2*a*, *b*).

Description.—Specimen no. 23422 (fig. 91) suggests a tall, slender-shanked, gazelle-like form, being of very small cross-section and yet equalling in length that of large specimens of *Procamelus robustus*. As viewed from the front this cannon bone is remarkably long and slender; in lateral aspect the posterior outline is somewhat bowed



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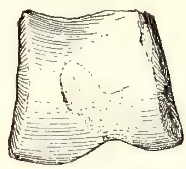

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Figs. 95 and 96. Cervidae. Fragments of a lower tooth, no. 24036, and of an astragalus, no. 23779, × 1. Eden beds, California.

through thickening in the middle region; posteriorly a deep groove marks the junction of the two metapodials, which are firmly coössified except at the distal separation. The distal ends are but little expanded transversely; they are more than proportionately developed laterally, the trochleas having a strong backward inflection. The keels of the plantar surface are very prominent.

Measurements of Metapodial No. 23422

Total length	*a*380 mm.
Length of distal separation	65
Anteroposterior diameter of single trochlea	32
Transverse diameter of single trochlea	23

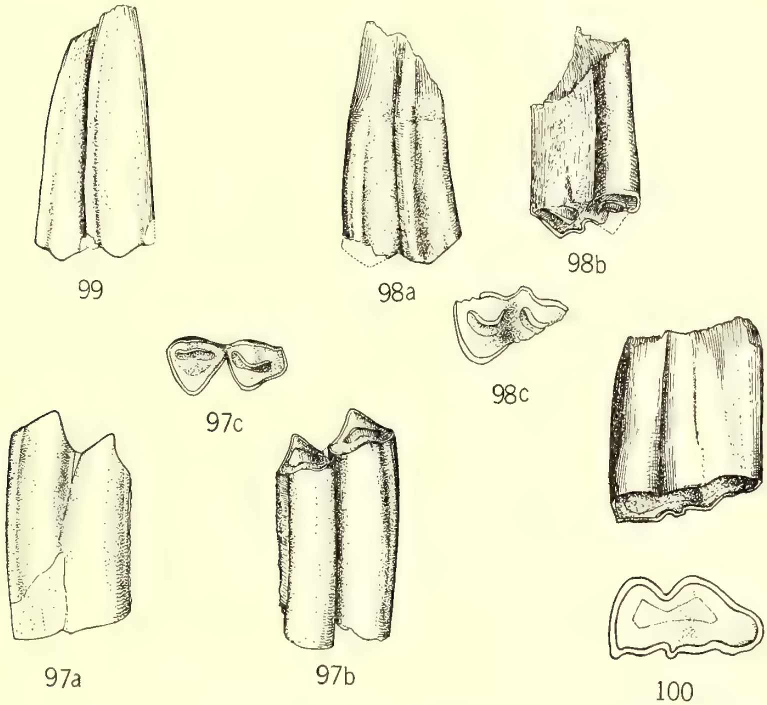
a, approximate.

Cervidae

CERVID, sp.

Material.—The portion of a small premolar, no. 24036 (fig. 95), and the inferior half of a medium sized astragalus, no. 23779 (fig. 96); both in Univ. Calif. Coll. Vert. Pal.

Discussion.—The occurrence of the portion of a short crowned premolar is of great interest as indicating the presence of at least one brachyodont deer-like form among the tall-crowned antelope of this horizon. It may represent the dentition of the cervid species, whose presence is further suggested by the portion of an astragalus (fig. 96).



Figs. 97*a*–97*c*, 98*a*–98*c*–100. *Antilocapra?*, n. sp. Cheek teeth, × 1. Figs. 97*a* to 97*c*, $M_{\overline{2}}$, no. 23408, outer, inner and occlusal views; figs. 98*a* to 98*c*, upper molar, no, 23406, outer, inner and occlusal views; fig. 99, portion of upper molar, no. 23780; fig. 100, $M^{\underline{3}}$, no. 23407, occlusal and inner views. Eden beds, California.

Antilocapridae

The portion of a forked horn or horn core and specimens of long, narrow-crowned, upper and lower molar teeth are here tentatively referred to the antilocaprine group on the evidence of a slight resemblance of the horn core, and of the marked similarity of the associated teeth to those of the living form. The material may represent a single species or widely differing species.

ANTILOCAPRA?, n. sp.

Material.—A forked horn or horn core, no. 23421 (fig. 101); an upper molar, no. 23406 (figs. 98*a*–98*c*); and a last upper molar, no. 23407 (fig. 100); all from Univ. Calif. loc. 3269. A portion of an upper molar, no. 23780 (fig. 99), and of a lower molar, no. 23408 (figs. 97*a*–97*c*), from Univ. Calif. loc. 3266. All in Univ. Calif. Coll. Vert. Pal.

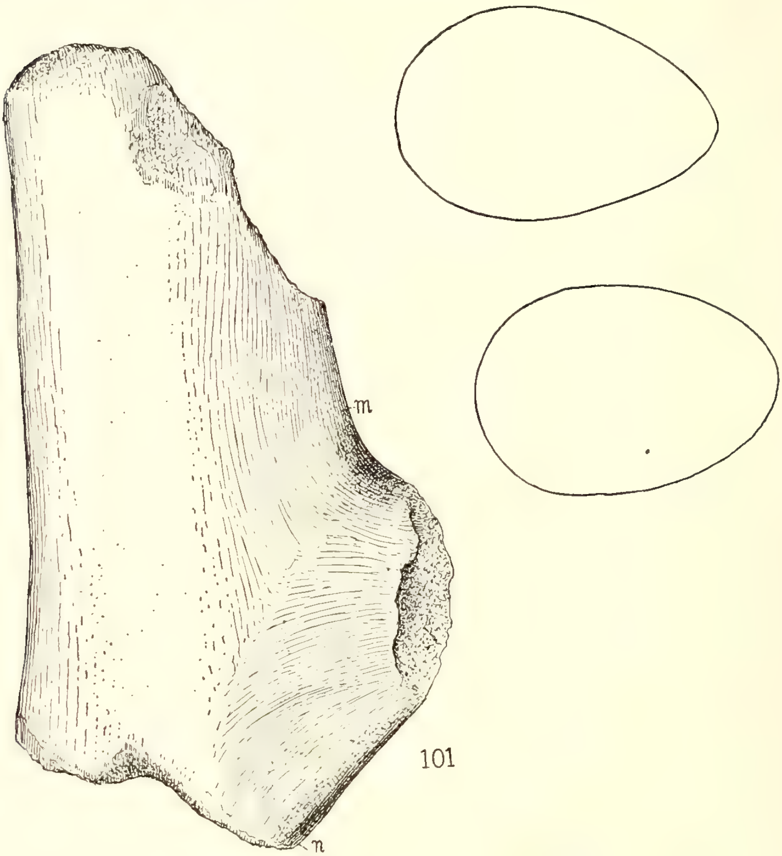


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Fig. 101. *Antilocapra?*, n. sp. Horn core, with outlines of cross sections, no. 23421, × 1. Eden beds, California.

Description.—The horn specimen (no. 23421, fig. 101) may represent either: (1) some unknown Pliocene form near *Antilocapra,* the specimen somewhat resembling the left horn core of a large prong horn, but being of greater size with the portion above the fork thickening instead of tapering (cross-section posterior to fork in no. 23421 27.5 mm. and in a large antelope 21 mm.); or (2) the beam section of an antler of some large cervid, which is strongly suggested on

comparison with elk-like forms though no such cervid is yet known from so early an American horizon.

The lower molar (no. 23408, figs. 97*a*–97*c*) is of long-crowned, antelopine form, resembling a tooth from Thousand Creek which has been tentatively referred to *Sphenophalos* Merriam.[54] Anteroposteriorly it is longer than the Nevada tooth, and the corresponding teeth of the living antelope, but transversely is somewhat narrower. Other slight differences between the specimens and teeth of *Antilocapra* are the somewhat greater development of the styles, and the absence of the strong backward inflection of the inner tooth lobes.

Comparative Measurements of Teeth

	No. 23408	Antilocapra*	No. 12604 referred to Sphenophalos or Ilingoceros*
$M_{\overline{3}}$, anteroposterior diameter of crown	16.4 mm.	14.4 mm.	14.5 mm.
$M_{\overline{3}}$, transverse diameter of crown	7.3	7.7	7

* Teeth are but slightly worn and the measurements are taken at the middle of the crown.

Though the anterior crescent of the third upper molar (no. 23407, fig. 100) has disappeared, and only a trace of the posterior crescent remains, the tooth is still noticeably long-crowned. The specimen is of the same relative proportions as no. 23408 (figs. 97*a*–97*c*) and is believed to represent the same species. The inner lobes, in a more modified degree than in specimen 23408, are less angular and less forwardly directed than those of the otherwise very similar last superior molars of *Antilocapra*.

Comparative Measurements

	No. 23407	Mature male antelope Univ. Calif. Mus. Vert. Zool. no. 8298	Old specimen Univ. Calif. Coll. Vert. Pal. no. 19231
M^3, anteroposterior diameter	20.3 mm.	20 mm.	19.5 mm.
M^3, transverse diameter	10	10	10

The portion of an upper molar, no. 23406 (figs. 98*a*–98*c*), and the shell of a second, no. 23780 (fig. 99), from Univ. Calif. loc. 3266, are long-crowned and of the general relative proportions of the former teeth and may represent the same species. Tooth no. 23406 is considerably worn and in size lies intermediate between two specimens from Thousand Creek. The styles project less than in the present day pronghorn.

[54] Merriam, John C. Tertiary Mammal Beds of Virgin Valley and Thousand Creek of Northwestern Nevada. Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 285–292, 1911.

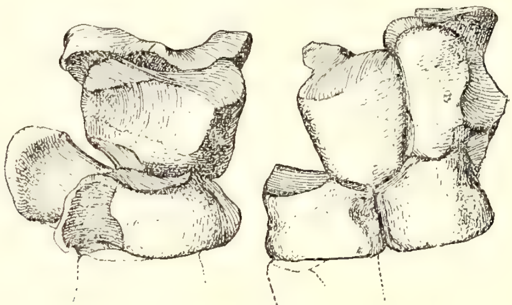
COMPARATIVE MEASUREMENTS

	Upper Molar No. 23406	Antilocapra Univ. Calif. Coll. Vert. Pal. no. 8929
Anteroposterior diameter	15 mm.	15.5 mm.
Transverse diameter	10	11.5

MERYCODUS?, Sp., OR ILINGICEROS?, sp.

Material.—Portions of a small carpus, metacarpus, and radius, Univ. Calif. Coll. Vert. Pal. no. 23432 (figs. 102*a*, 102*b*), Univ. Calif. loc. 3274.

Discussion.—The carpal bones, and portions of metacarpus and radius, Univ. Calif. Coll. Vert. Pal. no. 23432 (figs. 102*a*, 102*b*) belong



Figs. 102*a*, 102*b*. *Antilocapra?*, n. sp. Incomplete carpus, no. 23432, × 1. Fig. 102*a*, lateral view; fig. 102*b*, front view. Eden beds, California.

to a smaller animal than the cervid-like tooth and astragalus listed above, and may represent a small species near *Merycodus*, or some antelope form such as *Ilingoceros.*

EQUIDAE

The collection consists of some two hundred non-associated and associated cheek teeth showing a considerable range of pattern and size, a large number of incisors, and certain limb elements.

Individual variation and the stage of wear where there is scarcity of material often erroneously suggests multiplicity of form. Many cross-sections have been made in the case of the present teeth, and they have assisted in determining to what extent the characters noted in these specimens have been due to age. As none of the upper teeth occurred definitely associated with the lower teeth, and as teeth and

limb material were never closely associated, each of the three is considered in a separate division. The writer has divided the upper teeth into two main groups, and tentatively the lower teeth into two corresponding groups, as follows:

Upper Cheek Teeth

(1) *Group of Pliohippus osborni.*—A group (see descriptions below) in which the specimens exhibit strong *Equus* character, in the marked anterior projection of the protocone and the grooving of its inner margin, a degree of this anterior projection being retained in even much worn teeth. Two forms are recognized: (1) *Pliohippus osborni*, n. sp.; and (2) *P. osborni*, subform A. The distinction between the two, however, which is mainly one of size, may be sexual. This group apparently represents an important and unrecognized transitional stage in equine development. Somewhat similar but more *Equus*-like teeth have been noted in the overlying beds (see figs. 38*a*–38*b*, 39*a*–39*b*, *Pliohippus francescana minor*, n. subsp.).

(2) *Group of Pliohippus edensis.*—A more typical *Pliohippus* group (see description, p. 388), in which in moderately worn teeth the protocone is narrow and backwardly directed and in which in aged teeth the protocone tends to thicken and to become more oval in cross-section. Three forms are recognized: (1) *Pliohippus edensis*, n. sp.; (2) *P. edensis*, subform A, suggesting *P. spectans* Cope of the Rattlesnake; and (3) *P. edensis*, subform B. At the end of the group are listed certain indeterminate teeth, including those of the milk series.

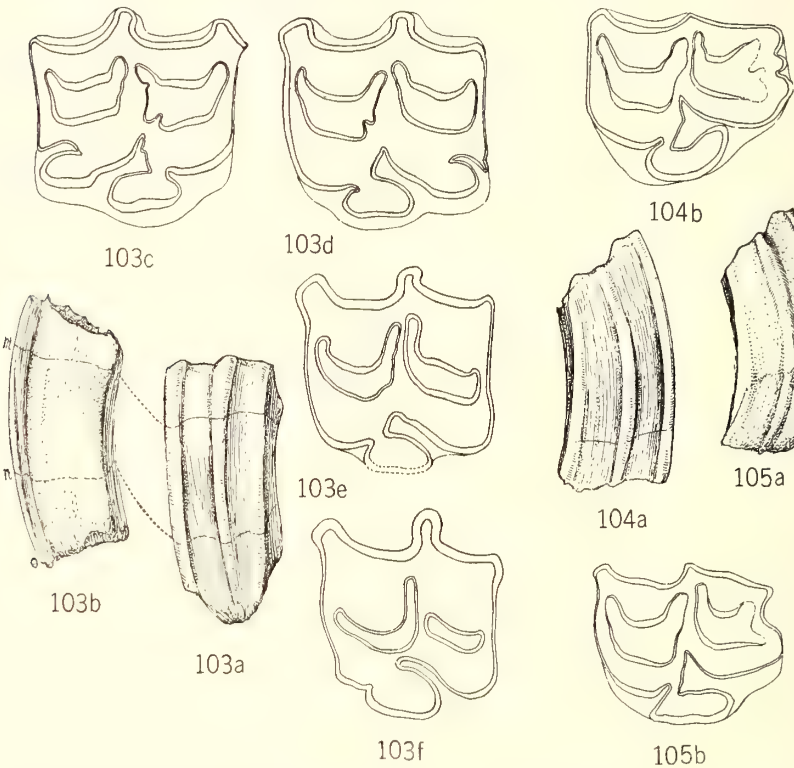
PLIOHIPPUS OSBORNI, n. sp.

Type.—A large moderately worn upper cheek tooth from the right side, Univ. Calif. Coll. Vert. Pal. no. 23787 (figs. 103*a*–103*f*, 129), Univ. Calif. loc. 3269.

Referred specimen.—A large third upper molar, Univ. Calif. Coll. Vert. Pal. no. 23338 (figs. 104*a*, 104*b*), same locality.

Characters.—The strong tendency towards the *Equus* rather than the *Pliohippus* type, as shown by the elongated anteroposterior and thick transverse diameters of the protocone, together with the broad production of the anterior corner of the protocone and the indentation of its inner margin. A corresponding equine flatness of the outer walls of the protoconid and hypoconid is noticed in certain of the lower teeth occurring in the same beds (see figs. 127 and 128).

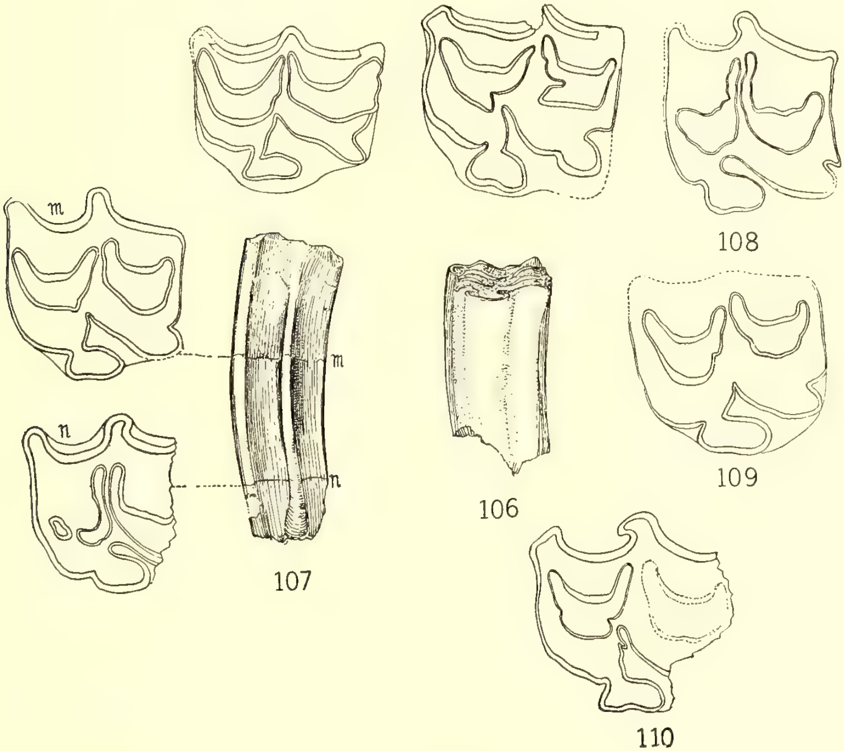
Description.—The angle of the external faces of the type specimen, the transverse breadth of the anterior edge, the anteroposterior length, and heaviness of the parastyle suggests P^4. The type and referred specimen are of large size in comparison with the teeth of the subform and with the more typical *Pliohippus* teeth from the same beds, compare third molars referred to type (figs. 104*a*–104*b*) and to



Figs. 103*a* to 105*b*. *Pliohippus osborni*, n. sp. Premolar and molar teeth. Figs. 103*a*–103*f*, type, no. 23787: fig. 103*a*–103*b*, outer and front views, × ½; fig. 103*c*, occlusal view, × 1; figs. 103*d*–103*f*, sections through m, n and o respectively. Figs. 104*a*, 104*b*, referred M^3, no. 23338: fig. 104*a*, outer view, × ½; fig. 104*b*, occlusal view, × 1. Figs. 105*a*, 105*b*, *Pliohippus osborni*, subform A, small M^3, no. 23350: fig. 105*a*, outer view, × 1; fig. 105*b*, occlusal view, × 1. Eden beds, California.

subform A (figs. 105*a*–105*b*). The crowns are long and well curved. The parastyle is relatively strong, the mesostyle well developed. The protocone is large (the anteroposterior diameter being twice the transverse), the cusp projects considerably anteriorly, and is slightly indented in the inferior margin; the main postprotoconal valley is relatively narrow, and is extended at the head, where a slight subsidiary fold is developed. Cross-sections of the type specimen (figs.

103*d, e, f*) illustrate moderately and excessively worn stages, showing the following age characters: (1) the retention to a considerable degree of the protocone characters of the moderately worn state; and (2) the usual transverse narrowness and accompanying constriction and attenuation of the fossettes and styles; (3) the narrowing of the post-protoconal valley and loss of accessory fold.



Figs. 106 to 110. *Pliohippus osborni,* subform A. Premolar and molar teeth. Fig. 106, premolar, no. 24037, occlusal view, × 1, inner view, × ½; fig. 107, referred molar, no. 23334, occlusal view, × 1; outer view, × ½; fig. 108, referred molar, no. 23336, occlusal view, × 1; fig. 109, referred molar, no. 23332, occlusal view, × 1; fig. 110, referred molar, no. 23346, occlusal view, × 1. Eden beds, California.

PLIOHIPPUS OSBORNI, subform A

Type specimen.—A slightly worn tooth from the left side of the upper jaw, Univ. Calif. Coll. Vert. Pal. no. 24037 (fig. 106), Univ. Calif. loc. 3269.

Referred material.—Premolar, no. 23334 (fig. 107), and nos. 23336, 23332, and 23346 (figs. 108, 109, 110); and M^3, no. 23350 (figs. 105*a*–105*b*). All in Univ. Calif. Coll. Vert. Pal.; all from same locality as the type.

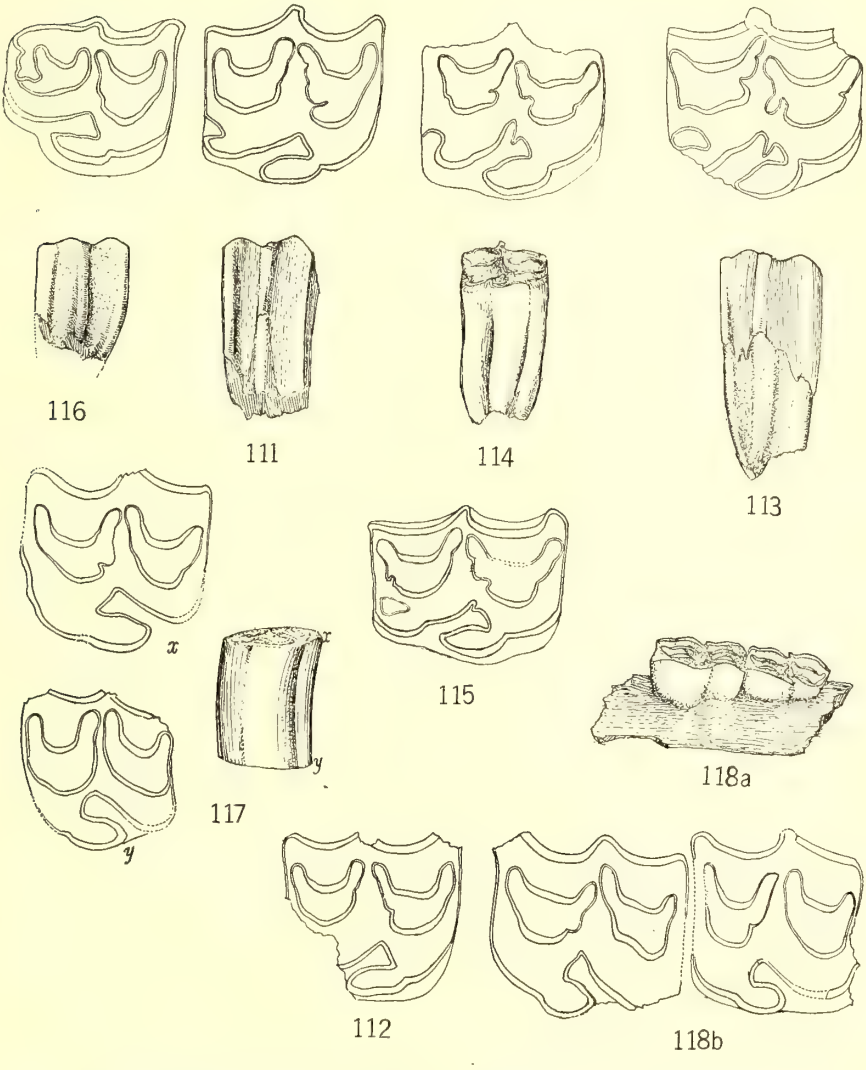
Characters.—Relative small size, well illustrated by a comparison of the referred third molar (figs. 105*a*–105*b*), with that of the referred third molar of *P. osborni* (figs. 104*a*–104*b*).

Description.—All small teeth, such as no. 24037 (fig. 106), which resemble the type *P. osborni* in the unusual form of the protocone, are placed in this subdivision. Tooth no. 24037 (fig. 106) is believed to represent P^3 on account of transverse proportions and the extension of the anterior horn of the postfossette with respect to the posterior horn of the anterior fossette. It is more markedly narrow in its proportions than the type specimen of *P. osborni* (no. 23787, figs. 103*a*–103*c*). This noticeable transverse narrowness is characteristic of the referred smaller teeth. It is noted especially in no. 23334 (fig. 107), but is seen in cross-section to be greatly influenced by the state of wear, the tooth becoming thicker transversely and narrower anteroposteriorly in the worn state. The lakes in moderately worn specimens are small proportionally, with single folds in their opposite margins; in more worn teeth they become increasingly broader; in well worn teeth they narrow and tend to disappear.

Comparative Measurements

	Pliohippus osborni no. 23787 type	P. francescana no. 23275 referred	P. osborni, A sp. no. 24037 type	P. edensis (spectans-like) no. 24039 type	P. edensis edensis no. 23331 type
Greatest anteroposterior diameter	27 mm.	30.3 mm.	26 mm.	26.6 mm.	23.7 mm.
Greatest transverse diameter	27	28.7	25.5	27.2	23.2
Greatest anteroposterior length of metaconid-metastylid	10	8.6	8.2	7.4	8.2

Conclusion.—The type specimen of *Pliohippus osborni* strangely approximates a P^3 referred to the smaller of the two horses occurring in the overlying San Timoteo beds (*P. francescana minor,* no. 23275, figs. 38*a*–38*b*, 39*a*–39*b*; folder 3, fig. 4). It differs widely and markedly from the average *Pliohippus* types seen in the upper teeth of its own horizon, which have more of the typical *Pliohippus* primitiveness. The smaller teeth of subform A may represent no more than a sexual variation. A large lower tooth, no. 23222 (fig. 127) is seen to be of advanced form when compared with the average lower teeth from the Eden formation, and in character and size might well belong with the advanced *P. osborni* type represented by the upper tooth.



Figs. 111–118*b*. *Pliohippus edensis,* n. sp. Premolar and molar teeth. Fig. 111, type specimen, molar no. 23331, occlusal view, × 1, outer view, × ½; fig. 112, referred molar, no. 23233, occlusal view, × 1; fig. 113, referred premolar, no. 23329, occlusal view, × 1, outer view, × ½; fig. 114, referred premolar, no. 23284, occlusal view, × 1, inner view, × ½; fig. 115, referred premolar, no. 23333, occlusal view, × 1; fig. 116, a last molar, no. 23337, occlusal view, × 1, outer view, × ½; fig. 117, referred molar, no. 23207, inner view, × ½, with cross sections through x and y, × 1; figs. 118*a*, 118*b*, jaw fragment with M^1 and M^2, no. 23349, fig. 118*a*, inner view, × ½; fig. 118*b*, occlusal view, × 1. Eden beds, California.

PLIOHIPPUS EDENSIS, n. p.

Type specimen.—A small, moderately worn upper cheek tooth from the right side, Univ. Calif. Coll. Vert. Pal. no. 23331 (fig. 111), Univ. Calif. loc. 3269.

Referred specimens.—Premolars, nos. 23329, 23284, 23333 (figs. 113–115); molars, nos. 23233 and 23207 (figs. 112, 117); M^3, no. 23337 (fig. 116); and fragment of jaw containing P^4 and M^1, no. 23349 (fig. 118). All specimens in Univ. Calif. Coll. Vert. Pal.; all from Univ. Calif. loc. 3269.

Characters.—The moderate size, the long, narrow, curved crowns, the thin, elliptically-shaped, and backwardly directed protocone which entirely lacks anterior projection.

Description.—A comparison of the type specimen (no. 23331, fig. 111) and the directly referred specimens suggests that the type represents P^4, the other teeth respectively three P^3s, an M^1(?), an M^2(?), and an M^3. The type specimen is moderately worn (compare fig. 118 and tooth sections, fig. 117). The styles are light. The narrow, elliptically-shaped protocone is bent characteristically backward, and is quite lacking in anterior extension. In moderately worn teeth the protocone tends to narrow in transverse diameter toward the rear of the series. In worn teeth, such as are illustrated by the sections of a molar (no. 23207, fig. 117) and P^4 and M^1 (fig. 118), the protocone is seen to retain much of its original form though tending to shorten slightly anteroposteriorly and broaden transversely. The postprotoconal valley in the type specimen and in the referred molars is narrow and without the accessory fold which occurs in the wider valleys of the three upper third premolars. The lakes as compared with those of the following type are of very moderate size, being smallest in the molars; their margins are somewhat indented, especially in the more slightly worn upper third premolars.

Measurements of Teeth of Pliohippus edensis, n. sp.

	No. 23331	No. 23329	No. 23333
Anteroposterior diameter of crown	23.7 mm.	25.8 mm.	25.9 mm.
Transverse diameter of crown	23.2	24	21
Length of protocone of crown	8.2	9	8

PLIOHIPPUS EDENSIS, subform A, PLIOHIPPUS SPECTANS–LIKE

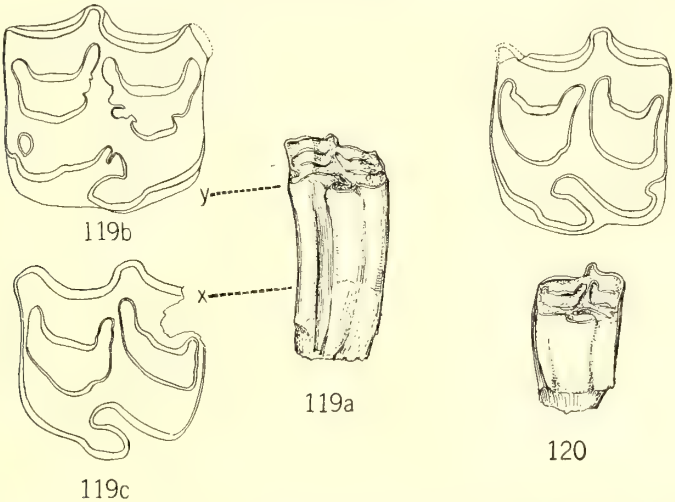
Type.—A large and slightly worn tooth from the right side, Univ. Calif. Coll. Vert. Pal. 24039 (figs. 119*a*, 119*b*, 119*c*).

Referred material.—A worn molar, Univ. Calif. Coll. Vert. Pal. no. 23328 (fig. 120); both teeth from Univ. Calif. loc. 3269.

Additional material.—Second premolar, Univ. Calif. Coll. Vert. Pal. no. 23234 (fig. 122*b*), Univ. Calif. loc. 3269.

Characters.—The larger size, the relatively anteroposterior shortness of the protocone and great transverse depth of the lakes in both the moderately and much worn stages; the general *Pliohippus spectans*-like appearance.

Description.—Specimen no. 24039 (figs. 119*a*–119*c*) is but moderately worn and is believed to represent P^4. It is of markedly greater



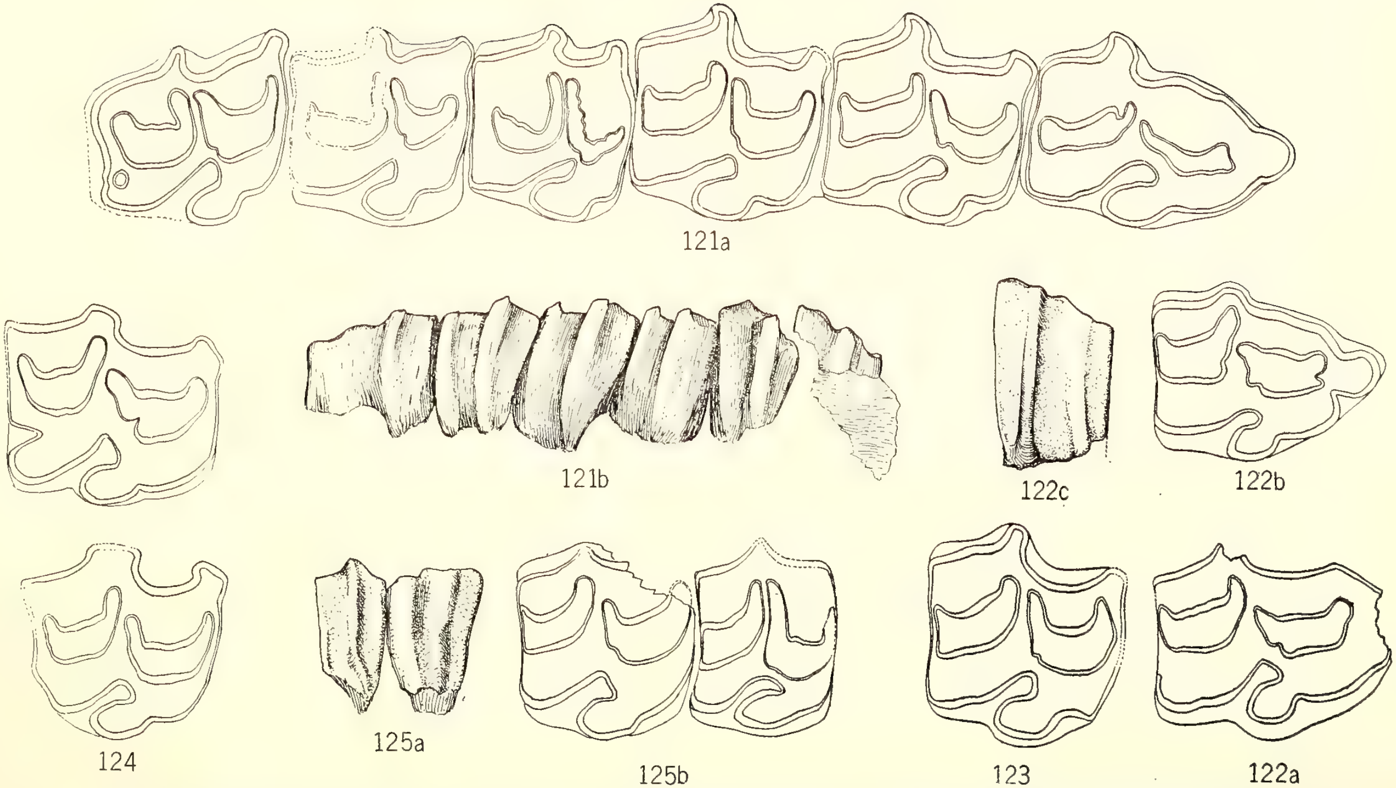
Figs. 119 to 120. *Pliohippus edensis*, subform A, *P. spectans*-like. Figs. 119*a*–119*c*, premolar, no. 24039, inner view, × ½; occlusal view and cross section, × 1. Fig. 120, referred molar, no. 23328, inner view, × ½; occlusal view, × 1. Eden beds, California.

size than the premolars of the preceding section, and the protocone is proportionately smaller. The lakes are large and deep. The convolutions in their inner borders disappear in age as seen in cross-section. The cross-section suggests the referred worn molar (no. 23328, fig. 120). This last tooth, though differing in actual measurements, being of smaller size and more worn, strongly resembles the *P. spectans* type described by Cope from the Rattlesnake.

Comparative Measurements

	Pliohippus edensis, subform A, Univ. Calif. Coll. Vert. Pal. 24039 type	P. edensis subform A, referred Univ. Calif. Coll. Vert. Pal. 23328	P. spectans type specimen* Am. Mus. Cope Coll. 8183
Anteroposterior diameter	26.8 mm.	24 mm.	27 mm.
Transverse diameter	26.2	25	25.2
Length of protocone	7	7.5	7.5

* Measurements taken from cast of type specimen.



Figs. 121*a*–121*b*, 122*a*–122*c*, 123–124, 125*a*–125*b*. *Pliohippus edensis*, n. sp. and subsp. Upper dentition. Figs. 121*a*, 121*b*, *P. edensis*, subform B, type specimen, upper cheek tooth series, no. 23193: fig. 121*a*, occlusal view, × 1; fig. 121*b*, outer view, × ½. Figs. 122*a* to 122*c*, *P. edensis*, n. sp., P^2: fig. 122*a*, no. 24285, subform B, referred second premolar, occlusal view, × 1; fig. 122*b*, no. 23234, small form, occlusal view, × 1; fig. 122*c*, no. 23234, outer view, × ½. Fig. 123, *P. edensis*, subform B, tooth, no. 23219, occlusal viey, × 1. Fig. 124, two cross sections of a premolar, no. 23351, × 1. Figs. 125*a*, 125*b*, *P. edensis*, subform B, referred M^1 and M^2, no. 23327; fig. 125*a*, outer view, × ½; fig. 125*b*, occlusal view, × 1. Eden beds, California.

PLIOHIPPUS EDENSIS, subform B

Type.—A complete series from the right side of the upper jaw, Univ. Calif. Coll. Vert. Pal. no. 23193 (figs. 121*a*–121*b*), Univ. Calif. loc. 3269.

Referred material.—Second premolar, no. 24285 (fig. 122*a*); molar, no. 23219 (fig. 123); cross section of no. 23351 (fig. 124); M^1, M^2, no. 23327 (figs. 125*a*–125*b*), Univ. Calif. loc. 3301; all others, Univ. Calif. loc. 3269. All in Univ. Calif. Coll. Vert. Pal.

Characters.—The large size of the much worn teeth and the transverse thickness and inflection of the inner margins of the protocones, as compared with *Pliohippus edensis,* typical form, and with *P. edensis,* subform A.

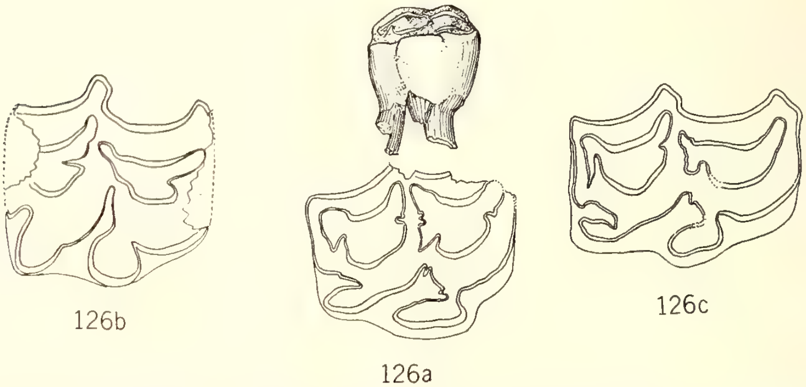
Description.—The teeth are very much worn. They are of large size, the protocones are more than relatively large, and their inner borders have a more angular inflection than those of other *Pliohippus edensis* teeth. The considerable size of the teeth is illustrated by comparison of the P^2 of type series and of referred specimen no. 24285 (fig. 122*a*) with the small *P. edensis*-like P^2, no. 23234 (figs. 122*b, c*). The inflection of the inner border of the protocone is illustrated by comparison of the P^4 of type series and specimen 23219 (fig. 123) with the *P. edensis* type tooth (fig. 111). Certain somewhat similar teeth from the Eden representative of equally worn stages have protocones tenting more to the *P. edensis* type (see cross-sections no. 23351, and molars no. 23327, figs. 124, 125*a*–125*b*). These are only very tentatively placed in this section. The series of the B subtype is believed to represent a variation of the general *Pliohippus edensis* form. Cross-sections (figs. 107, 103*e,* 108) show the protocones of specimens of *P. osborni* of a fully equal stage of wear still retaining a certain amount of the typical anterior projection.

PLIOHIPPUS UPPER MILK TEETH

Material.—A small section of an upper tooth, Univ. Calif. Coll. Vert. Pal. no. 23220 (fig. 126*b*), Univ. Calif. loc. 3269. Two upper milk teeth, Univ. Calif. Coll. Vert. Pal. nos. 23202, and 23330 (figs. 126*a, c*).

Description.—The tooth no. 23220 is of very peculiar pattern, but so fragmentary that the position of the section is undeterminable; it may represent a milk tooth. The protocone is remarkably oval in cross-section and, like the hypocone, is directed inward; the post-protoconid valley is greatly extended; the lakes are long and narrow. The tooth has some of the characters of the milk dentition; in its

square form, however, it differs from the usual milk tooth. It suggests in some ways *Pliohippus fairbanksi,* a form otherwise entirely unrepresented in the collection.



Figs. 126*a* to 126*c*. *Pliohippus* upper milk teeth. Fig. 126*a,* no. 23202, inner view, × ½; occlusal view, × 1. Fig. 126*b,* no. 23220, occlusal view, × 1; fig. 126*c,* no. 23330, occlusal view, × 1. Eden beds, California.

The teeth nos. 23202 and 23330 (figs. 126*a,* 126*c*) have some of the characters seen in the advanced *Pliohippus,* but their very narrow and short crowns indicate that they are milk teeth.

Lower Cheek Teeth

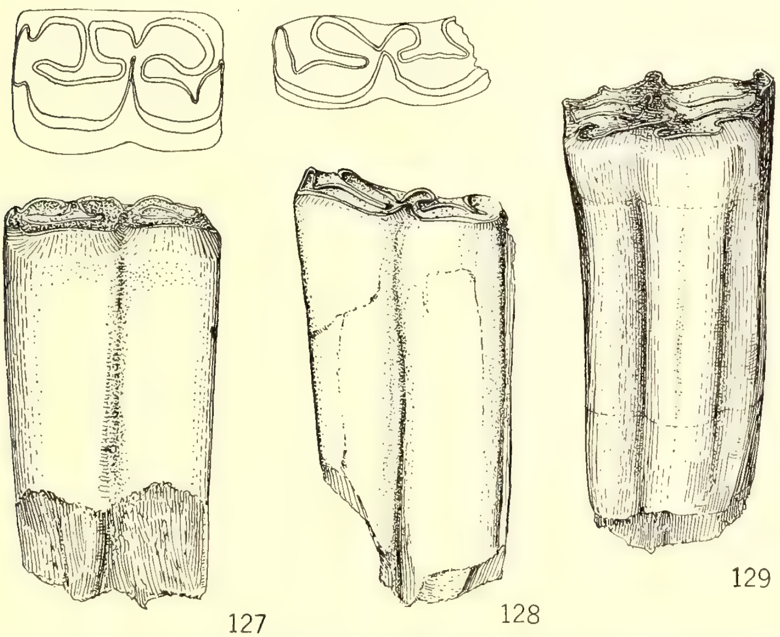
(1) A group (see description below) in which the specimens exhibit advanced *Equus* character, in the anteroposterior elongation of the metaconid-metastylid column, and in the flattening of the exterior faces of the protoconid and hypoconid. The section apparently embraces teeth of at least two subforms; these may correspond with the upper teeth described under *Pliohippus osborni* and *P. osborni,* subform A.

(2) To a second group (see figs. 132–157*c*) has been assigned the balance of the lower teeth, which though separable into several forms are all of general average *Pliohippus* character, and are believed referrable to forms lying close to the new species *Pliohippus edensis* and subforms described under Upper Teeth. The subdivisions of this group are: (1) Medium sized lower teeth, near (?)*Pliohippus edensis,* n. sp.; (2) large lower cheek teeth near(?) subform B of the same; (3) teeth of narrow transverse diameter; (4) lower cheek teeth of remarkably small size and of uncertain relationship, and (5) specimens representative of the milk dentition.

Lower Cheek Teeth Tentatively Referred to Pliohippus osborni, n. sp.

Material.—An abnormally large tooth from the right side of the jaw, no. 23222 (fig. 127); and very tentatively placed with the same, a large molar, no. 23197 (fig. 128). Both specimens in Univ. Calif. Coll. Vert. Pal., Univ. Calif. loc. 3269.

Description.—The large lower tooth (no. 23222, fig. 127) is very *Equus*-like, especially in the flatness of the inner walls of the proto-



Figs. 127 to 129. *?Pliohippus osborni,* n. sp. Premolar teeth, outer and occlusal views, × 1. Fig. 127, no. 23222; fig. 128, no. 23197; fig. 129, *Pliohippus osborni,* n. p., upper premolar of type specimen, no. 23787, inner view, × 1. Eden beds, California.

conid and hypoconid. The relative anteroposterior length of the crown, the transverse narrowness of the anterior end, and the depth of the fold between the protoconid and hypoconid point to the specimen representing the last premolar. The groove, or gutter, of the metaconid-metastylid column, unlike *Equus,* is sharp and deep; the wings of the metaconid and metastylid are broadly expanded and unsymmetrical, that of the metaconid being especially enlarged and produced forward and inward. The exterior faces of the protoconid

and especially of the hypoconid are, as above noted, unusually flat for *Pliohippus.* The fold between the protoconid and hypoconid extends in the form of a fine line within the mouth of the metaconid-metastylid, suggesting such a development and extension in the molars as is alone seen in the lower molars of the following section and in those of *Pliohippus francescana* of the overlying beds. The entoconid is very large and full. The specimen is very tentatively referred to the large upper tooth described as *Pliohippus osborni* no. 23787 (figs. 129, 103*a*–103*f*).

Second specimen (no. 23197, fig. 128).—This tooth is long-crowned, of large size, and of exceptional proportions, the triturating surface being long anteroposteriorly and very narrow transversely. The wings of the metaconid-metastylid column are widely extended, the gutter is deep, and the exterior faces of the hypoconid are relatively flat, both protoconid and hypoconid being very narrow transversely. The specimen is evidently a molar. In character it is very like the larger specimen (no. 23222, fig. 127), excepting for its narrowness, though fully as great a reduction in the transverse breadth of the molars over the premolars at times is known to occur. The two teeth may represent the same species.

MEASUREMENTS OF PLIOHIPPUS OSBORNI

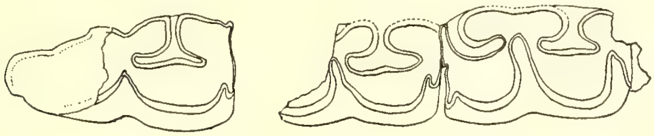
	Premolar no. 23222	Referred molar no. 23197
Anteroposterior diameter of crown	28.3 mm.	27.7 mm.
Transverse diameter of crown	14.3	10.6
Anteroposterior length of metaconid-stylid column	16.6	14

LOWER TEETH, TENTATIVELY REFERRED TO PLIOHIPPUS OSBORNI, subform A

Material.—A section of the mandible from the right side containing $P_{\overline{4}}$, $M_{\overline{1}}$, $M_{\overline{2}}$, and $M_{\overline{3}}$, Univ. Calif. Coll. Vert. Pal. no. 23510 (fig. 131), Univ. Calif. loc. 3269. An $M_{\overline{1}}$ with attached portion of $P_{\overline{3}}$ and an associated portion of $P_{\overline{2}}$, Univ. Calif. Coll. Vert. Pal. no. 23286 (fig. 130); the fragment of a mandible with $P_{\overline{2}}$ and $P_{\overline{3}}$, no. 24040. Both from the same locality as the type.

Characters.—Proportionately great anteroposterior extension of the metaconid-metastylid column and openness of the gutter; the presence of a small accessory fold at the anterior inner corner of the protoconid in $M_{\overline{1}}$; the large size of $M_{\overline{1}}$ as compared to $P_{\overline{4}}$; the deep, evenly concave, *versus* angularly convex, outer margin of the

protoconid, and the resulting unusual, rounded contour of the sides of the valley that divides the parastylid and metastylid; the considerable production of the fold between the protoconid and hypoconid within the mouth of the metaconid-metastylid column of $P_{\overline{4}}$, and the sudden and marked increase in the size and production of this fold in $M_{\overline{1}}$.



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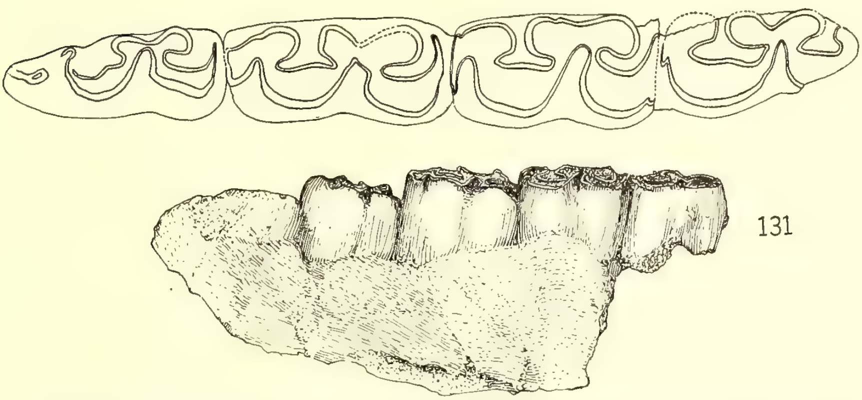

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Figs. 130, 131. *?Pliohippus osborni,* **subform A.** Lower cheek teeth. Fig. 130, two premolars and one molar associated, no. 23286, referred specimen, occlusal view, × 1. Fig. 131, $P_{\overline{4}}$ to $M_{\overline{3}}$, no. 23510, type, occlusal view, × 1; outer view, × ½. Eden beds, California.

MEASUREMENTS OF P. OSBORNI, SUBFORM A

	No. 23510			No. 23286
	$P_{\overline{4}}$	$M_{\overline{1}}$	$M_{\overline{2}}$	$M_{\overline{1}}$
Anteroposterior diameter of crown		27.3 mm.	28.5 mm.	25.2 mm.
Transverse diameter of crown	12.6 mm.	12.7	11.1	13.3
Anteroposterior length of pillar	13.6	15.1	13.5	15

Discussion.—Except for the suggested sharpness of the gutter of the metaconid-metastylid pillar, the teeth in the flatness of their inner faces and the great anteroposterior extension of the metaconid-metastylid would indicate the presence of an *Hipparion* form. This elongation of the metaconid-metastylid column of the new teeth is shown in comparison to that occurring in hipparions from the Rattlesnake and Ricardo Pliocene, as well as in *Merychippus* and *Pliohippus* in the following table.[55]

[55] *Hipparion* and *Merychippus* data through the kindness of Professor John C. Merriam.

Comparative Length of Metaconid-Metastylid Column in Pliohippus, Hipparion and Merychppus

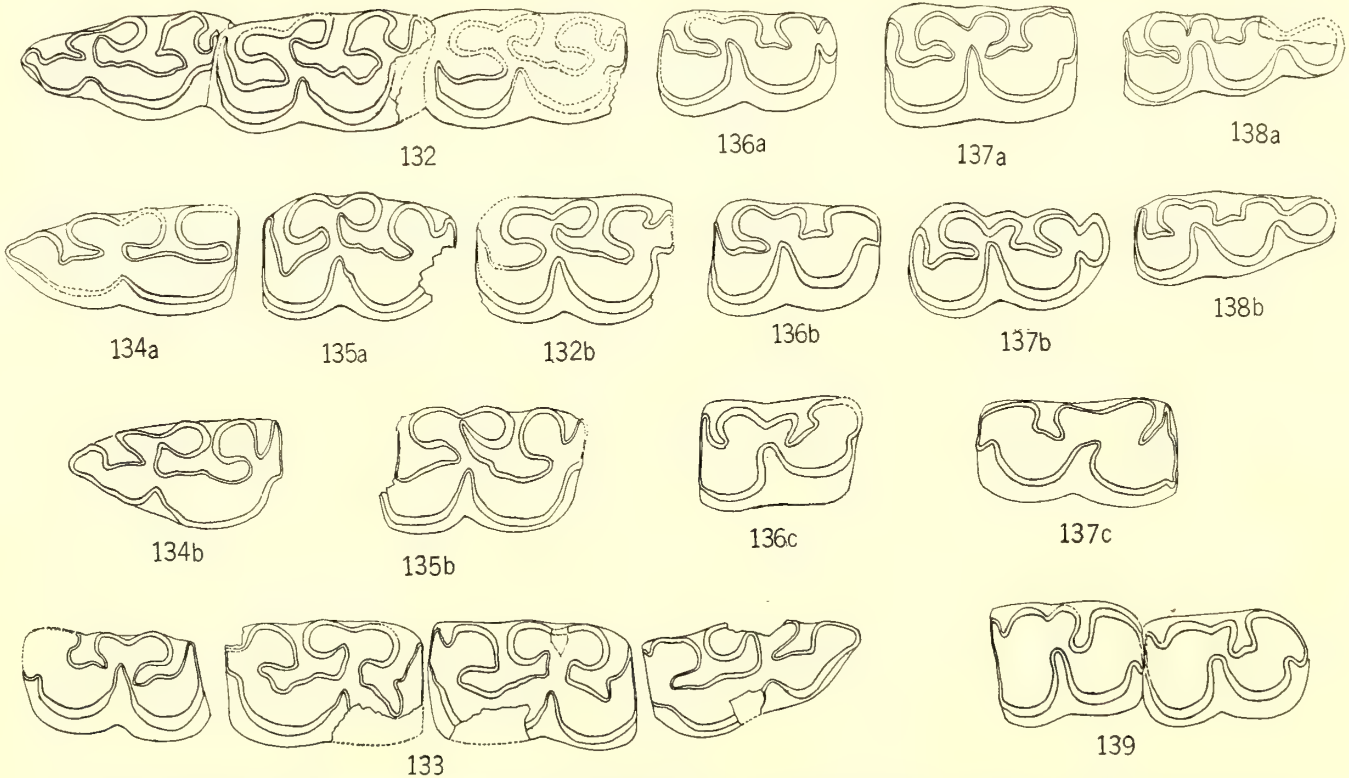
	Ratio of length of crown to anteroposterior diameter of metaconid-metastylid pillar	Ratio of breadth of crown to anteroposterior diameter of metaconid-metastylid pillar
No. 23510, $M_{\overline{1}}$	.56 mm.	1.19 mm.
No. 23510, $M_{\overline{2}}$	.50	1.21
No. 23286, $M_{\overline{1}}$	.60	1.12
H. leptode from Rattlesnake no. 544, $P_{\overline{4}}$	.60	1.22
H. mohavense no. 19788, $P_{\overline{4}}$	.62	1.23
H. mohavense, type, no. 21348, $P_{\overline{4}}$	.60	1.10
Merychippus, average, $P_{\overline{4}}$	.36–.47	.77–.93
Pliohippus, average, $P_{\overline{4}}$	.50	.90

Remarks.—The type specimen represents a somewhat immature individual, $M_{\overline{3}}$ being but slightly worn, and not having come into function. $M_{\overline{1}}$ of the referred specimen is slightly heavier than that of the type, is in better condition, and illustrates the characteristic points to better advantage. In this specimen (fig. 130) there is a suggestion of a fold on the anterior border of the hypoconid of $P_{\overline{4}}$ as seen in a Rattlesnake specimen (Univ. Calif. Coll. Vert. Pal. no. 544). The parastylid is moderately well produced. The entoconid is remarkably full and round. The groove of the elongated metaconid-metastylid column is deeper in $P_{\overline{4}}$ and much less flat than in $M_{\overline{1}}$. These specimens are but very tentatively referred to *P. osborni*, subform A.

MEDIUM SIZED LOWER TEETH, NEAR (?)PLIOHIPPUS EDENSIS, n. p.

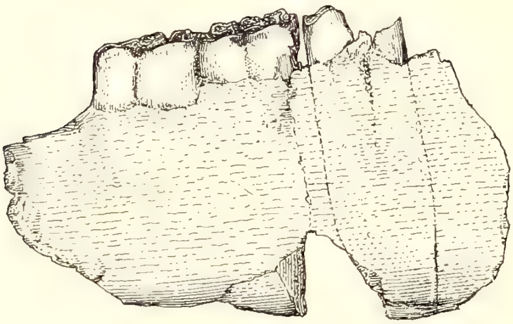
Material.—A left ramus containing $P_{\overline{2}}$ to $P_{\overline{4}}$, no. 23195 (figs. 132*b*, 140), Univ. Calif. loc. 3269; and associated series representing $P_{\overline{2}}$ to $M_{\overline{1}}$, no. 23194 (figs. 133, 141*c*), Univ. Calif. loc. 3267; premolars, nos. 23231 and 23784 (figs. 135*a*–135*b*); $P_{\overline{2}}$, nos. 23214 and 23209 (fig. 134*a*–134*b*); molars, nos. 23215 (figs. 136*a*, 141*a*), 23201, 23211 (figs. 136*b*–136*c*); molars, nos. 23352 (figs. 137*a*, 141*b*), 23226, 24283 (figs. 137*b*–137*c*); $M_{\overline{3}}$, nos. 23230, 23287 (figs. 138*a*–138*b*); two very worn molars in jaw fragment, no. 23289 (fig. 139). All specimens in Univ. Calif. Coll. Vert. Pal.

Characters.—The medium sized and generalized *Pliohippus* form; exterior faces of protoconid and hypoconid convex; groove between metaconid and metastylid column shallow and open; the moderate anteroposterior length of wings of metaconid-metastylid column, which is greater in premolars than in molars.



Figs 132 to 139. *?Pliohippus edensis, n. sp.* Lower cheek teeth, occlusal view, × 1. Fig. 132, $P_{\overline{2}}$ to $P_{\overline{4}}$, no. 23195, and fig. 132*b*, cross section of $P_{\overline{4}}$. Fig. 133, three premolars and an associated molar, no. 23194. Two $P_{\overline{2}}$s: figs. 134*a*, no. 23214; fig. 134*b*, no. 23209 (reversed). Fig. 135*a*, 135*b*, premolars: fig. 135*a*, no. 23231; fig. 135*b*, no. 23784 (reversed). Figs. 136*a* to 136*c*, molars: fig. 136*a*, no. 23215; fig. 136*b*, no. 23201; fig. 136*c*, no. 23211 (reversed). Figs. 137*a* to 137*c*, molars: fig. 137*a*, no. 23352 (reversed, see fig. 141*b* for lateral view); fig. 137*b*, no. 23226; fig. 137*c*, no. 24283. Figs. 138*a*, 138*b*, $M_{\overline{3}}$: fig. 138*a*, no. 23230; fig. 138*b*, no. 23287. Fig. 139, $M_{\overline{1}}$ and $M_{\overline{2}}$, no. 23289. Eden beds, California.

Discussion.—The section of a mandible, no. 23195 (figs. 132, 140), containing three premolars, and a second specimen representing $M_{\overline{1}}$, no. 23215 (figs. 136*a*, 141), are but slightly worn, and illustrate the tall, downwardly tapering crowns of the unworn stage. The $M_{\overline{1}}$ is in about the same stage of wear as that represented in the cross-section of $P_{\overline{4}}$ of the jaw specimen. The teeth of an associated series, no. 23194 (fig. 133), are somewhat more worn, but generally similar to those of the former specimen, no. 23195. The small molar tooth of no. 23194 is of considerable interest in showing the reduction in size of the posterior portion of the series in this type. The small jaw fragment containing $M_{\overline{1}}$ and $M_{\overline{2}}$ (fig. 139) is important in showing the relatively small size of $M_{\overline{2}}$ of the worn teeth.



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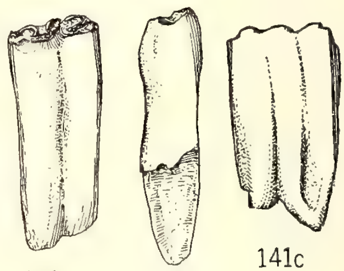


141a 141b 141c

Figs. 140 to 141*c*. *?Pliohippus edensis*, n. sp. Lower cheek teeth of medium size, lateral view, × ½. Fig. 140, three premolar teeth, no. 23195 (for occlusal view see fig. 132). Fig. 141*a*, molar, no. 23215 (for occlusal view see fig. 136*a*); fig. 141*b*, no. 23352 (for occlusal view see fig. 137*a*); fig. 141*c*, $P_{\overline{4}}$, no. 23194 (see fig. 133 for occlusal view of series). Eden beds, California.

MEASUREMENTS

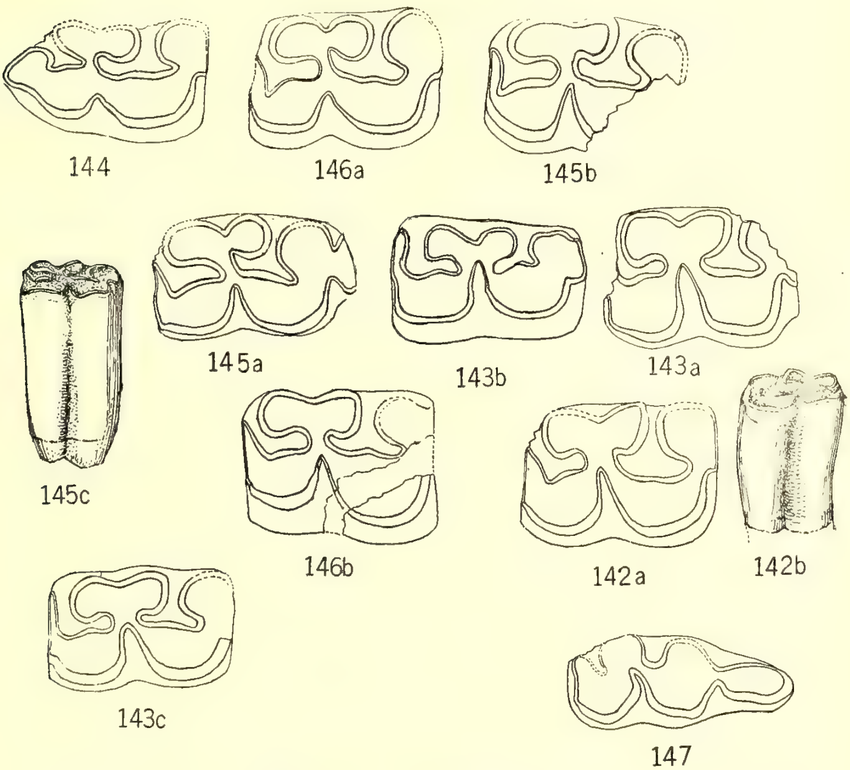
	No. 23195 $P_{\overline{3}}$	$P_{\overline{4}}$	No. 23352 Molar	No. 23226 Molar
Anteroposterior length of crown	25.5 mm.	25 mm.	25 mm.	25.2 mm.
Transverse diameter of crown......	12.5	14.5	13.2	13.2
Anteroposterior length of metaconid-metastylid column	12.9	12.6	12	12.3

LARGE LOWER CHEEK TEETH, NEAR (?)PLIOHIPPUS EDENSIS SUBFORM B

Material.—A second premolar, no. 23326 (fig. 144); premolars, nos. 23285, 23295 (figs. 146*a*–146*b*), 23212, 23223 (figs. 145*a*–145*c*, 145*b*); molars, nos. 23232, 23224, 23296A, 23294 (figs. 142*a*–142*b*, 143*a*, 143*b*, 143*c*); and last molar, no. 23288 (fig. 147). All in Univ. Calif. Coll. Vert. Pal., all Univ. Calif. loc. 3269.

Characters.—The relatively large size, great transverse thickness, and general *Pliohippus* form. The transversely expanded wings and resulting bold appearance of the metaconid-metastylid column, and the convexity of the outer edges of the protoconid and hypoconid.

Description.—The teeth are of much heavier proportions than the average of the former section. All of the specimens excepting no.



Figs. 142*a* to 147. *?Pliohippus edensis,* subform B. Large lower cheek teeth, occlusal views, × 1; inner views, × ½. Figs. 142*a*, 142*b*, molar, no. 23232. Fig. 143*a*, no. 23224; fig. 143*b*, no. 23296A; fig. 143*c*, no. 23294. Fig. 144, $P_{\overline{2}}$, no. 23326. Figs. 145*a*, 145*c*, premolar, no. 23212; fig. 145*b*, premolar, no. 23223. Figs. 146*a*, and 146*b*, nos. 23285, 23295 (reversed). Fig. 147, $M_{\overline{3}}$, no. 23288. Eden beds, California.

23212 (fig. 145*a*) are considerably worn. Certain of the more worn specimens are somewhat approached in appearance and size by the larger teeth of the preceding section and no more than a sexual difference may exist. This is suggested by the presence of a worn molar, no. 23294 (fig. 143*c*) that below the point of greatest transverse thickness is no larger than certain teeth of the preceding section.

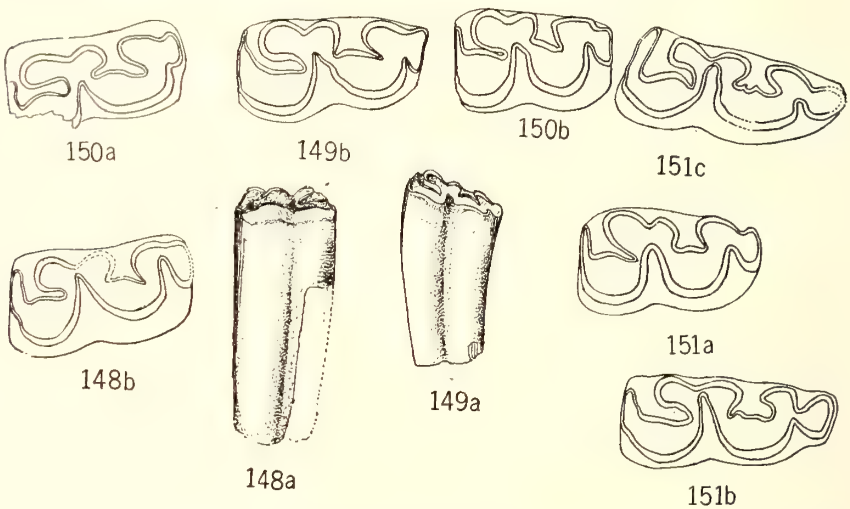
MEASUREMENTS

Premolars:	No. 23212	No. 23223
Anteroposterior diameter	24.2 mm.	26.3 mm.
Transverse diameter	15.4	15.5
Anteroposterior length of metaconid-metastylid column	13.8	15.1
Molars:	**No. 23295**	**No. 23232**
Anteroposterior diameter	25.8	24.5
Transverse diameter	16	17.5
Anteroposterior length of metaconid-metastylid column	14.5	15

LOWER CHEEK TEETH, NEAR (?)PLIOHIPPUS EDENSIS

These teeth are of narrow transverse diameter, and moderate size.

Material.—Molars, no. 23296 (figs. 148*a*–148*b*), no. 23298 (fig. 150*a*), no. 24229 (fig. 150*b*); and last molars, nos. 23293, 23297 and 23291 (figs. 151*a*, *b*, *c*), all from general Univ. Calif. loc. 3269. All in Univ. Calif. Coll. Vert. Pal.



Figs. 148*a* to 151*b*. *?Pliohippus edensis*, n. sp. Narrow type of cheek teeth; occlusal views, × 1; outer views, × ½. Figs. 148*a*, 148*b*, molar, no. 23296. Figs. 149*a*, 149*b*, molar, no. 24228. Figs. 150*a*, 150*b*, nos. 23298, 24229. Figs. 151*a* to 151*c*, $M_{\overline{3}}$, nos. 23291, 23293, 23297. Eden beds, California.

Characters.—The medium size, accompanied by transverse narrowness of the crown, and the great convexity of the inner margin of the protoconid and hypoconid.

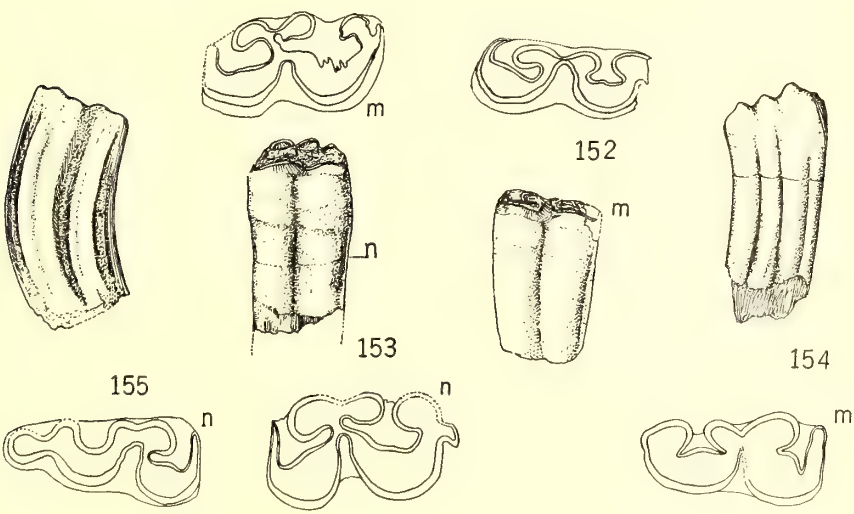
Description.—Several of the teeth are considerably worn. The specimens all have the character of molars, being thickest transversely at the anterior corner, and having the deep production of the fold between the protoconid and hypoconid. A specimen representing

the average of these teeth might be considered as greatly worn, and on that ground referred to the smaller of the two foregoing typical series, were it not: (1) for the presence of other greatly worn molars already referred to that section; and (2) for tooth no. 23296 (figs. 148*a*–148*b*), which though long-crowned and comparatively little worn, illustrates the same characters seen in the other narrow teeth. Tooth no. 24228 (figs. 149*a*–149*b*) shows a tendency to the even, oval form in the valley bounding the protoconid of the $M_{\overline{1}}$ of the teeth described under subform A of *P. osborni*, from which it otherwise differs absolutely through lacking: (1) the great development of the fold between the protoconid and hypoconid; (2) the anteroposterior elongation of the metaconid-metastylid column; and (3) the great degree of flatness of the exterior faces of that more advanced tooth type.

LOWER CHEEK TEETH OF PLIOHIPPUS, indeterminate

Teeth of remarkably small size, and of uncertain form.

Material.—A premolar, no. 23292 (fig. 153); molars, nos. 23517 and 23290 (figs. 154, 152); and a last molar, no. 23227 (fig. 155). All from general Univ. Calif. loc. 3269. All in Univ. Calif. Coll. Vert. Pal.



Figs. 152 to 155. *Pliohippus*, indet. sp. Lower cheek teeth of very small size. Fig. 152, molar, no. 23290; m, outer view, × ½; occlusal view, × 1. Fig. 153, premolar, no. 23292, outer view, × ½; m, occlusal view, × 1; n, cross section, × 1. Fig. 154, molar, no. 23517, outer view, × ½; m, occlusal view, × 1. Fig. 155, $M_{\overline{3}}$, no. 23227, outer view, × ½; n, occlusal view, × 1. Eden beds, California.

Description.—The specimens represent peculiar and individual phases of specialization. They are all long-crowned and are remarkable for their transverse narrowness and generally small size.

A small, slighly worn premolar, no. 23292 (fig. 153), is of interesting and unusual type. A cross-section at the root shows the retention of the same characters in the more advanced stage of wear.

A long, narrow-crowned molar (no. 23290) is especially noticeable for its very small size, even in comparison with the following three small teeth. It somewhat suggests the constricted molar (no. 23197, fig. 128) described under the *P. osborni* group, but is infinitely smaller.

Molar no. 23517 (fig. 154) is somewhat larger than the last.

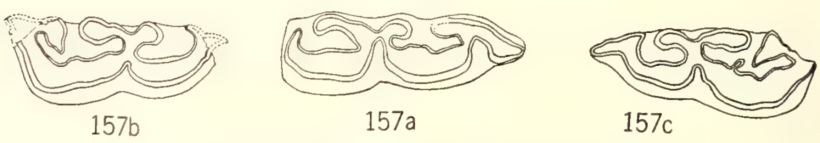
A third molar (no. 23227, fig. 155) is unique in having its root more strongly recurved and in being narrower transversely than other last molars of the collection.

Measurements

	No. 23290	No. 23517	No. 23292	No. 23227
Anteroposterior diameter	22.5 mm.	25 mm.	22 mm.	25.5 mm.
Transverse diameter	8.1	11.7	11	10.7
Anteroposterior length of metaconid-metastylid column	10.1	12.2	11.2	9

Lower Milk Teeth

Material.—Three milk cheek teeth, Univ. Calif. Coll. Vert. Pal. nos. 24054, 23513, 23514 (figs. 157*a*–157*c*).



Figs. 157*a* to 157*c*. *?Pliohippus*,. sp. Milk teeth, occlusal views, × 1. Fig. 157*a*, no. 23513; fig. 157*b*, no. 24232; fig. 157*c*, no. 23514. Eden beds, California.

Discussion.—The teeth are of very narrow form, are extended anteroposteriorly, and have very short roots, as is usual in the case of the milk dentition.

Limb Elements

Material.—(Pl. 49, figs. 1–10, and text fig. 158) Tibia, no. 23478 (pl. 49, fig. 1); metapodials, nos. 23454, 23457 (fig. 158); distal extremities of metapodials, nos. 23361, 23356, 23355, 23357, 23360, 23481, 23359; proximal portions of metapodials, nos. 23455, 23365; first phalanges, nos. 23367 and 23366; second phalanx, no. 23518; portions of astragalus, no. 23363, and calcaneum, no. 23456; pisiform, no. 23362; and various podial elements (pl. 49, figs. 2–10). All from Univ. Calif. general loc. 3269; all in Univ. Calif. Coll. Vert. Pal.

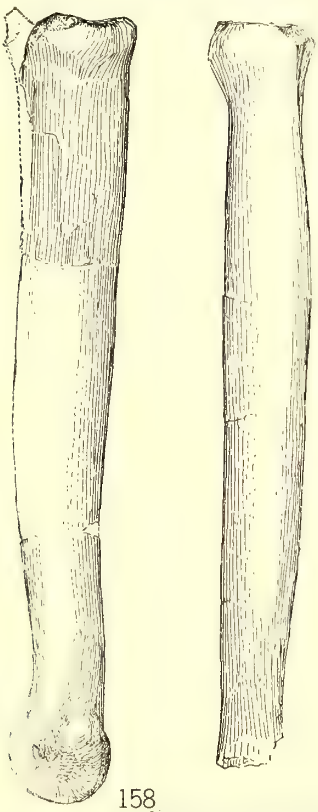


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Fig. 159. *Trilophodon shepardi* bones, nos. 23454 and 23457, lateral views, × ½. Eden beds, California.

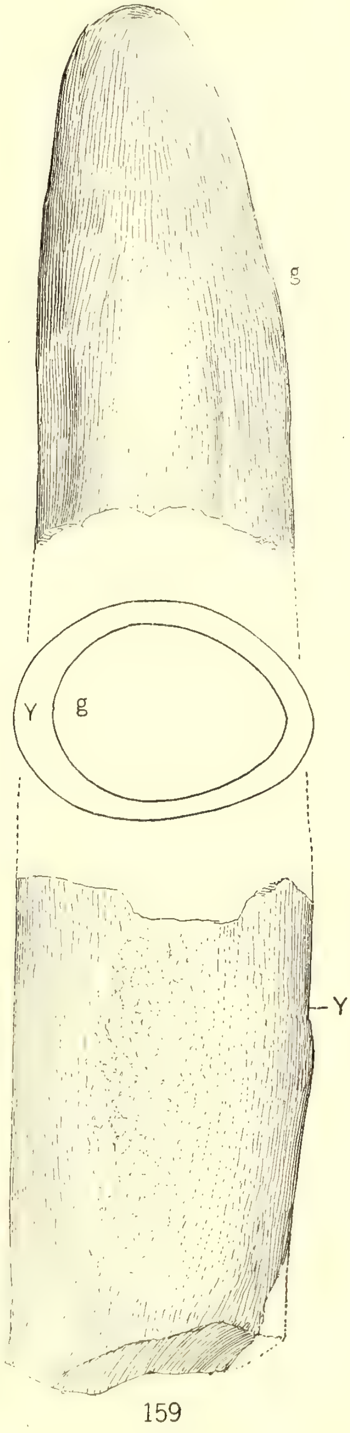

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Fig. 158. *Pliohippus,* sp. Cannon *edensis,* n. subsp. Distal end of small tusk, no. 24050, × 1. Eden beds, California.

The series of distal portions of metapodials again illustrates the considerable range of size among the Eden horses already noted in the teeth. The degree of deflection of the distal trochlea away from the axial line also varies, and on its part suggests the occurrence of more than one *Pliohippus* form. The tibia and cannon bones are those of an animal of light proportions, in this character more resembling the deer than the present day horse. The unciform facet of the third metacarpal and the cuboid facet of the third metatarsal are well developed.

Measurements of Limb Elements

Tibia:	No. 23478			
Greatest length of shaft	312 mm.			
Least diameter of shaft	25			
Metapodials:	No. 23454	No. 23457		
Greatest length of shaft	215	(225) mm.		
Greatest diameter of proximal end	(34)	40		
Greatest diameter of distal end	(35)			
Distal ends of metapodials:	No. 23361	No. 23356	No. 23355	No. 23357
Greatest lateral diameter of trochlea	41	(37)	33.5 mm.	31 mm.
Greatest transverse diameter of trochlea	33.5	28	27	(24)
Greatest anteroposterior diameter of trochlea	40	37	32	30
Phalanx I:	No. 23367	No. 23366		
Greatest length	65			
Greatest transverse diameter of proximal end	36.6	36		
Greatest transverse diameter of distal end	30			
Phalanx 2:				No. 23518
Greatest length				38
Greatest transverse diameter of proximal end				37.5

The figures in parentheses are approximate.

TRILOPHODON (TETRABELODON) SHEPARDI EDENSIS, n. subsp.

Type specimen.—The portion of a skull and posterior maxillaries, containing the last molar of the left side and a section of that of the right side, Univ. Calif. Coll. Vert. Pal. no. 23501 (fig. 160); two associated molars from the left and the right side respectively, Univ. Calif. Coll. Vert. Pal. 23503, 23504 (figs. 164, 162); and portions of premaxilla and tusks, Univ. Calif. Coll. Vert. Pal. no. 24047 (pl. 50), all from Univ. Calif, loc. 3269.

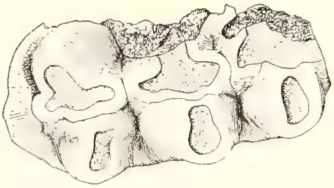
Referred material.—A lower molar, no. 23502 (fig. 165); portions of a worn upper molar, no. 23505 (fig. 161); parts of three worn molars, nos. 24049, 23507; a small premolar, no. 23506 (fig. 163); the distal portion of a small tusk, no. 24050 (fig. 159); the proximal section of a large tusk (specimen not retained, loc. 3265); portions of the supraorbital ridge, no. 24051, loc. 3266, of two scapulae, and various limb and foot elements. All in Univ. Calif. Coll. Vert. Pal.; all from Univ. Calif. loc. 3269, unless otherwise specified.

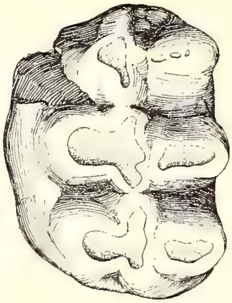
Characters.—The last molar with but four main transverse crests, the intermediate molars with three; the comparative simplicity of the tubercular arrangement, the lack of lateral cingula, and small size of the fourth crest and posterior extremity of the last molar; in moderately abraded teeth, the uniform trefoil character of the pattern of the outer lobes in the upper and of the inner lobes in the lower, and the single oval form of the corresponding opposite lobes in both.

MEASUREMENTS

	No. 23501 M^3	No. 23503 M^2?	No. 23501 M^1?	No. 23502 Lower molar	No. 23505 Upper molar
Anteroposterior diameter	150 mm.	128 mm.	120 mm.	130 mm.	— mm.
Greatest transverse diameter	80	84	84	(73)	76
Transverse diameter at first lobe	42	71	62	56	73
Transverse diameter at second lobe	42	72	69		67
Height of first lobe	60	23	32	50	23
Height of second lobe		32	34	34	
Distance intervening between inner edges of third tooth-lobes of last molar				75	
Height of second lobe above alveolus				62	
Distance between tusks, measured from center to center, no. 816				316	
Diameter of tusk at alveolus				90	× 100
Diameter of tusk 200 mm. from alveolus				82	× 100
Greatest diameter of large tusk of unpreserved specimen				200	
Distal diameter of small tusk, no. 1031				39	× 29
Length of distal portion of tusk at base, No. 1031				150	

The figure in parenthesis is approximate.





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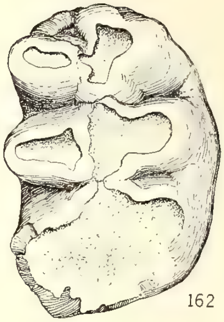

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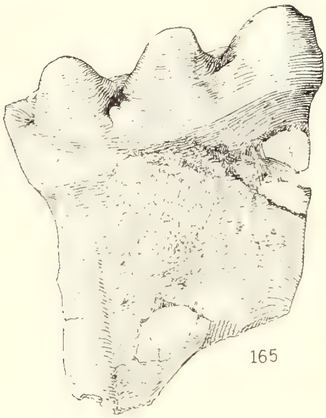

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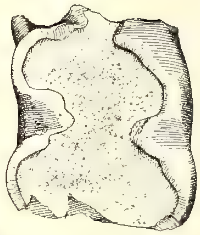

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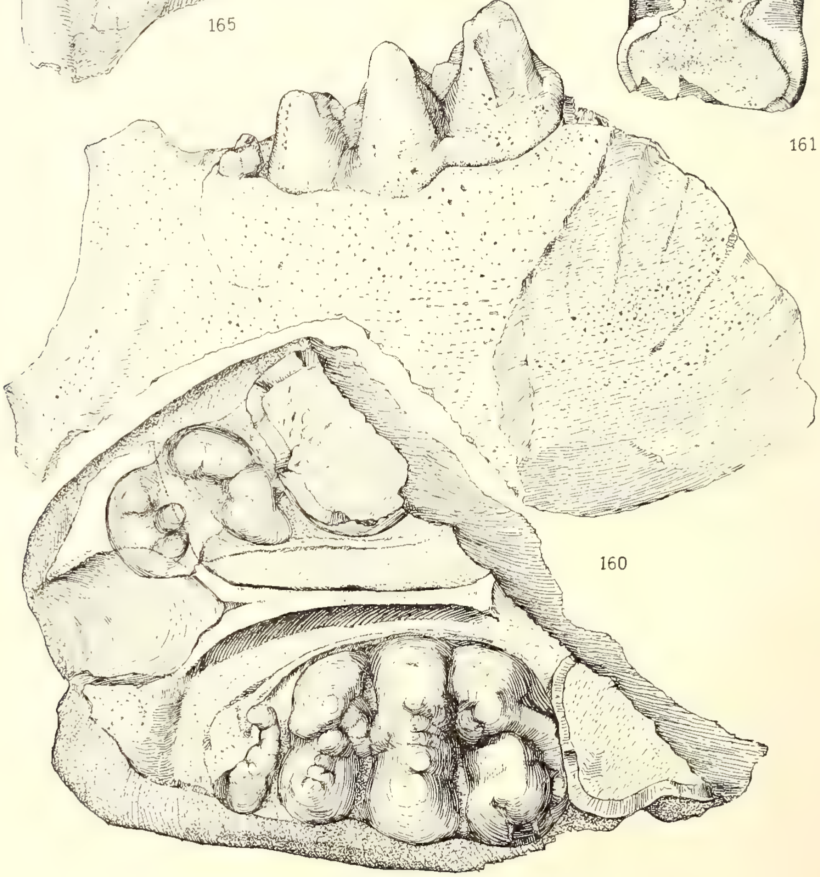

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Figs. 160–165. Described on page 407.

Description.—Portion of skull and posterior maxillaries of the type specimen: The fourth crest of the right molar (fig. 160) has but slightly protruded beyond the alveolus; the heels of both molars and the last lobe of the left molar are still buried beneath the pterygoid. A cross-section of the jaw, however, illustrates the very small amount of heel occurring in this form. The skull portion shows the foramen magnum, the vomer, and the edges of the great alveolar pouch limited posteriorly by the overarching process of the pterygoid.

The third molar in the right maxillary (no. 23501, fig. 160) is furnished with four main, deeply notched, outwardly diverging, transverse crests; and, as seen in cross-section of the opposite jaw, a rudimentary heel. The anteroposterior diameter of the specimen is slightly less than twice its transverse width, being widest at the second main crest and narrowest at the heel. The two forward crests have come into function, being abraded and polished; the posterior crests are still rugose. Each main crest consists of a large outer and larger inner pyramidal lobe, connected medially by three small subsidiary conules. Two of these are thrown off from the inner base of the outer lobe, and one from the inner base of the inner. Two additional conules rise laterally from the anterior and posterior faces of the inner lobes. They lie in a triangle with the tip of the main lobe and, abutting forward and aft against the corresponding conules of the next adjacent crests, form a low, anteroposteriorly directed ridge which obstructs the transverse valleys. In the worn stage this triangular grouping of the inner cusps and accessory conules gives rise to the trilobed pattern of the inner half of the upper teeth.

A second upper molar from the left side (no. 23503, fig. 164) is three lobed, and the two anterior crests are somewhat worn, especially toward the inner tooth margin. Two dentine tracts are exposed in each transverse crest, an outer tract of oval form appressed against an inner trilobed area. The lateral margins of the triangular area of adjacent crests abut against one another. A small pyramidal shelf at the posterior tooth extremity connects with the triturating surface by upwardly and inwardly directed ridges.

Figs. 160 to 165. *Trilophodon shepardi edensis,* n. subsp. Dentition. All figures × ⅓. Fig. 160, posterior portion of jaw of type with teeth, no. 23501, occlusal view (heel of right molar shown by dissection), and lateral view (position of heel shown by dotted line, portion of maxillary omitted); fig. 161, worn molar showing two lophs, no. 23505, occlusal view; fig. 162, upper molar, no. 23504, associated with jaw specimen, no. 23501, occlusal view; fig. 163, premolar, no. 23506, occlusal view; fig. 164, upper molar, no. 23503, associated with jaw specimen, no. 23503, occlusal view; fig. 165, lower molar, no. 23502, occlusal and lateral views. Eden beds, California.

A worn upper first molar from the left side (no. 23504, fig. 162) shows the anterior lobe greatly worn, the surface appearing as one large oval tract, though the shape of the outer half of the middle lobe suggests the trilobed pattern of the inner half.

A lower molar from the left side (no. 23502, fig. 165) is narrower transversely and tends to be longer anteroposteriorly than the upper molars of intermediate size mentioned above. It is three-lobed like the upper teeth, and of a similar but reversed pattern. The specimen appears slightly more worn than the upper tooth (no. 23503, fig. 164). The outer portions of the anterior two lobes are broken.

Specimen no. 23505 consists of the two anterior lobes of a greatly worn upper molar (fig. 161). The upper portions of the main lobes have been entirely ground away, the triturating surface on the exterior side being within 9 mm. of the root. The tooth pattern of a less worn stage is replaced by large, hollow, oval-shaped tracts of dentine, embraced by the enamel of the floors of the former transverse valleys.

A premolar (no. 23506, fig. 163) of very small size, is two-lobed, three-fanged, and much worn, little of the original pattern remaining. It is slightly larger than Professor Leidy's figure of the second upper premolar of *Mastodon floridanus*,[56] being of about the size of his accompanying cut of a second upper milk molar of the same species.

A fragment of a premaxilla containing portions of two tusks[57] is represented in plate 50. The specimens are of oval section, being composed of a central core surrounded by four concentric rings. The surface where unbroken is highly polished; a broad band of enamel is present on each; the inner texture is striated in the direction of the tusk curvature, which is distinctly inward and outward.

The collections include an eighteen-inch section of the basal portion of a much larger, but fragmentary tusk, measuring 200 mm. in diameter at the base, and associated with a well preserved pulp core measuring some 600 mm. in length. During the field work still another and larger tusk was uncovered, but disintegration had progressed too far to make the recovery of the specimen practicable.

Specimen no. 24050 represents the distal portion of a small tusk (fig. 159). The specimen is much flattened transversely, and a trace of enamel having a fine network-like pattern is visible on its basal portion. The tusk is evidently of a young animal.

56 Leidy, Joseph, and Lucas, Frederic A. Fossil Vertebrates from the Alachua Clays of Florida. Trans. Wagner Free Inst. Sci., Phila., vol. 4, pl. 4, 1896.

57 At the time of going to print the basal portions of the tusks have alone been recovered, the upper surface of the adjacent portions lying exposed in the quarry for eighteen inches, and the total length of the tusks being estimated at four feet.

Comparison.—In the three crests of the intermediate, the four crests of the last molars, and the simple pattern of the tubercles the Eden specimens differ markedly from the complex four-crested intermediate, and six-crested last molars of *Tetralophodon mirificus* Leidy of the Niobara and *T. campester* Cope of the Blanco. In the presence of but three transverse crests in the intermediate teeth, the new material comes within Matthew's recent definition of the genus *Trilophodon*[58] as distinguished from *Tetralophodon.*

The Eden teeth lack the elaborated complex pattern and tuberculated cingula of *Trilophodon floridanus* Leidy. The last molar of the new type specimen somewhat suggests the last lower molar from the San Joaquin Valley of California described by Leidy and tentatively referred by him to his type *Tetrabelodon shepardi.*[59] The resemblance is marked in the four well separated cross crests, in the very rudimentary heel of the last molar, and in the trefoil pattern exhibited by the outer halves of the transverse crests of the worn teeth and the small oval pattern of the inner halves.[60] Moreover, the tusks of the present specimen show the enamelled band noted by Leidy in his original description, which was based on the six inch section of tusk from Dry Creek, Stanislaus County.[61]

Further material from the San Joaquin vicinity and from Eden may possibly prove the Eden specimens, the last lower molar from Contra Costa County, the referred section of the small tusk (of Leidy's original description), and the portion of a second and somewhat broken molar from Stanislaus County, California, to represent one and the same species. For convenience in future reference, the Eden form is here referred to *T. shepardi* as a new subspecies under the name of the locality, *Trilophodon shepardi edensis.*

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[58] Matthew, W. D. Tertiary Mammalia Cope and Matthew, explanation plate 120. 1915.

[59] Leidy, Jos. Proc. Acad. Nat. Sci. Phil., pp. 98 and 99. Sept., 1870, and U. S. G. S. of Terrs., vol. V, p. 232. 1873.

[60] A four-crested last lower molar with rudimentary heel, from Oregon (Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, p. 134, fig. 3) somewhat suggests the present specimens, as do also the associated four lobed last molar and three lobed intermediate molar from Thousand Creek, Nevada (illustrated *l.c.* Merriam, vol. 6, pl. 33).

[61] A similar partial enamel covering has been noted on the fragments of two large tusks from the upper Miocene of Nevada (*l.c.* Merriam, vol. 9, p. 189).

Transmitted November 28, 1917.

EXPLANATION OF PLATE 43

Fig. 1. Bautista Badlands Area, southern California.

View looking west, down cañon of San Jacinto River. At left of foreground near mouth of South Fork (not shown) north-dipping Bautista sedimentary deposits are seen in contact with steeply pitching basement complex.

Fig. 2. San Timoteo Badland Area, southern California.

View eastward, toward Mt. Eden. San Timoteo exposures lie in foreground; Eden deposits in distance, about the south base and western corner of Eden Mountain. The fossil ledges lie to the north beyond and below the mountain crest.

Fig. 3. San Timoteo Badlands Area, southern California.

Looking west across the southern and steeply south-dipping limb of San Timoteo beds, at the edge of the Moreno San Jacinto Valley.

Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE 44

Fig. 1. Bautista Badlands Area, southern California.

Looking west across southwest corner of Bautista type locality; showing in left background the hills of the basement complex that line the south bank of Bautista Creek and limit the sedimentary area to the south and east.

Fig. 2. Bautista Badlands Area, southern California.

View northwest across Bautista deposits (foreground and center) toward the San Jacinto-Moreno Valley, the San Timoteo Badlands Area lying six miles to northwest beyond Mt. Claremont, in right background.

Fig. 3. Eden beds, southern California.

View north up Rabbit Cut, showing exposures of sharply north-dipping Eden shales.

Fig. 4. Eden beds, southern California.

View from crest above fossil ledges, looking southwest across the San Timoteo deposits; Eden beds skirting base of mountain, Moreno San Jacinto Valley in distance beyond the low San Timoteo Hills.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

EXPLANATION OF PLATE 45

Figs. 1-7, *Equus bautistensis*, n. sp., × ⅓. Bautista beds, California.

Fig. 1. Metacarpus, no. 23460.

Fig. 2. Portions of metacarpus, three phalanges, and portions of carpus, no. 23466.

Figs. 3*a*-3*c* (*a*) Metatarsus, and first and second phalanges, no. 23459; no. 23463, astragalus (*b*); calcaneum (*c*).

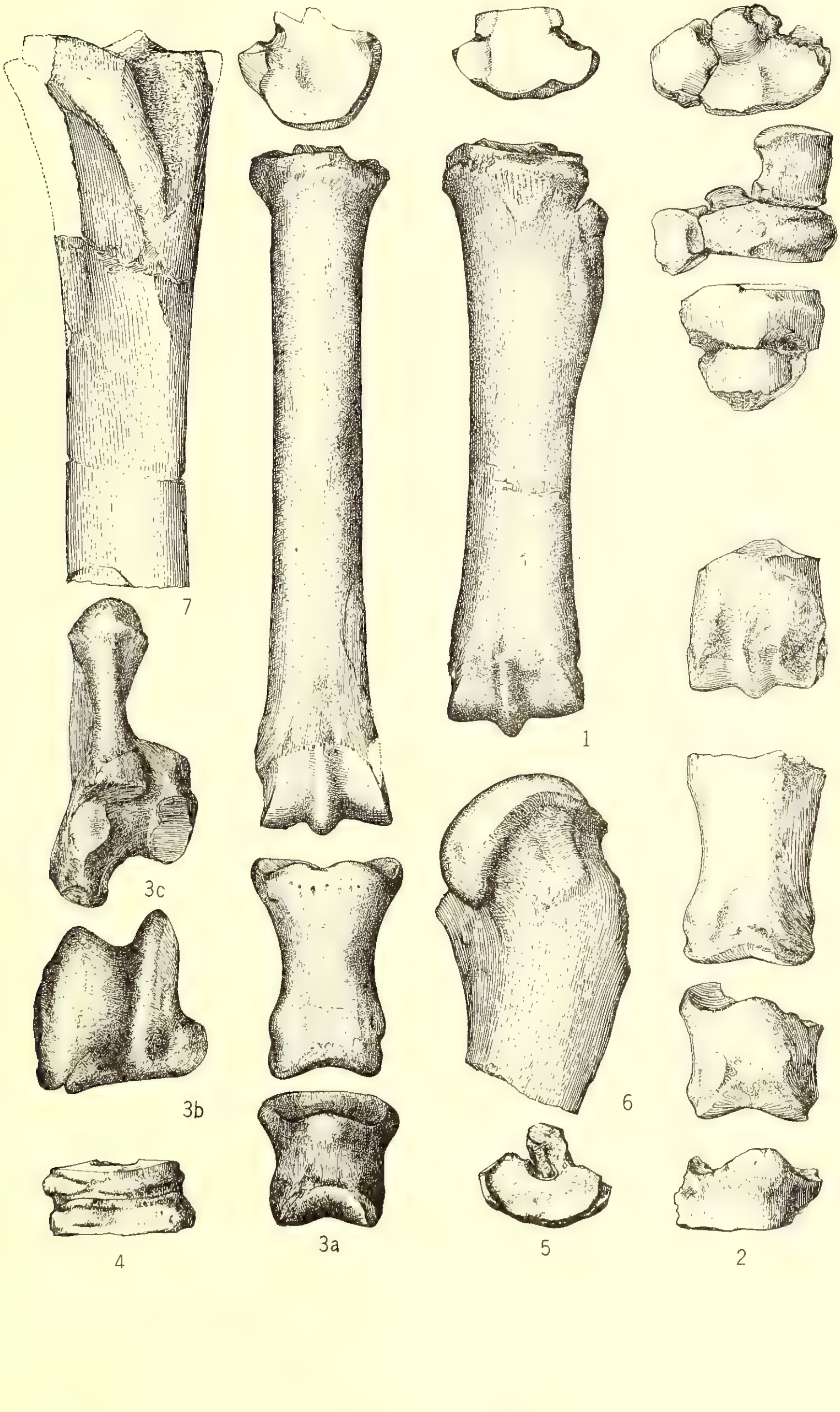
Fig. 4. Navicular and cuneiform bones, no. 23471A.

Fig. 5. Navicular bone, no. 23765.

Fig. 6. Proximal portion of femur, no 23489.

Fig. 7. Proximal portion of tibia, no. 23472.

All Univ. Calif. Coll. Vert. Pal.


7
1
3c
3b
6
3a
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2

EXPLANATION OF PLATE 46

Pliohippus francescana, *n.* sp., leg bones, × ⅓. Eden beds, California.

Fig. 1. Metacarpus, first and second phalanges, no. 23521

Fig. 2. Portions of metacarpus, first and third phalanges, nos. 23475, 23500.

Fig. 3. Metacarpus, no. 23474: *a*, front; *b*, rear view.

Fig. 4. Distal portion of metatarsus, no. 23476.

Fig. 5. Distal portion of first phalanges: *a*, no. 24230; *b*, no. 24231.

Fig. 6. Distal portion of calcaneum, no. 23764.

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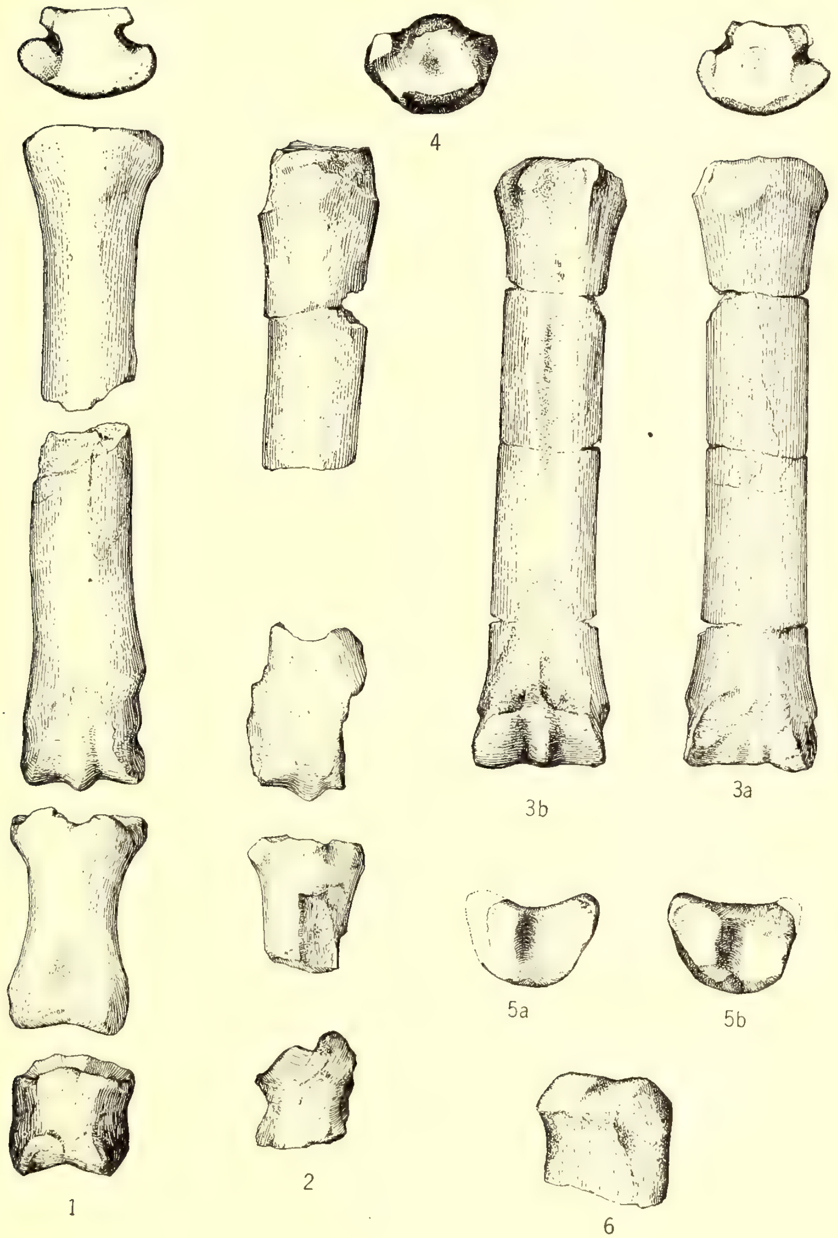
4
3b
3a
5a
5b
1
2
6

EXPLANATION OF PLATE 47

Pliauchenia. Eden beds, California. $\times \frac{1}{2}$.

Fig. 1. *P. merriami*, n. sp. Type specimen, portion of carpus and radius, no. 23483.

Fig. 2. *P. merriami*, n. sp. Type specimen, tarsus and portions of metatarsus and tibia, no. 23483.

Fig. 3. *Pliauchenia*, sp. A, referred radius, no. 23486 $\times \frac{1}{3}$.

Fig. 4. *P. merriami*, n. sp. Referred specimen, unciform, upper and lateral views, no. 23492.

Fig. 5. *Pliauchenia*, sp. A, type specimen, portion of carpus, no. 23484 $\times \frac{1}{3}$.

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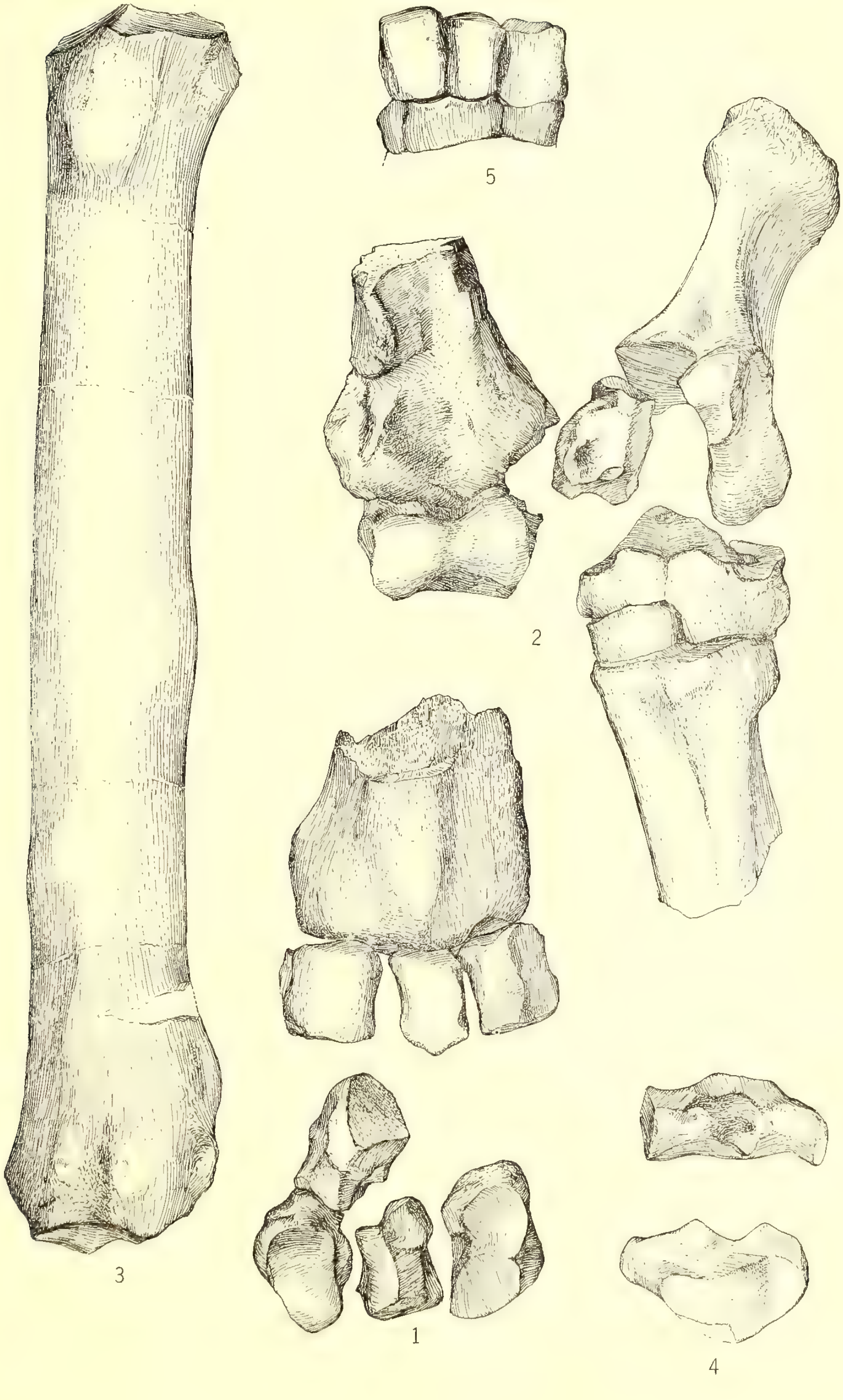
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4

EXPLANATION OF PLATE 48.

Camelidae, Eden beds, California: *Procamelus*-like specimens, figs. 1, 7, 9, *Pliauchenia*-like specimens, figs. 8, 10, 11.

Fig. 1. Distal portion of small cannon bone, no. 23498. × ⅔. (See fig. 91.)

Fig. 2. No. 23387. *a,* Distal portion of first phalanx; *b,* first phalanx trochlea portion.

Fig. 3. Second phalanx, no. 23385.

Fig. 5. First phalanx, trochlea portions: *a,* of no. 23386; *b,* of no. 23773 × ⅓.

Fig. 7. *a,* Scaphoid, no. 24035; *b,* cuneiform, no. 23399. × ⅔.

Fig. 8. *a, c,* Head and trochlea portions of first phalanx, no. 23392; *b,* head portion of first phalanx, no. 23393.

Fig. 9. *Procamelus*-like ulna-radius head, no. 23482. × ⅓.

Fig. 10. *Pliauchenia*, species A. Portion of ulna-radius and humerus, no. 23484.

Fig. 11. *Pliauchenia merriami*, portion of ulna-radius and humerus of type, no. 23483.

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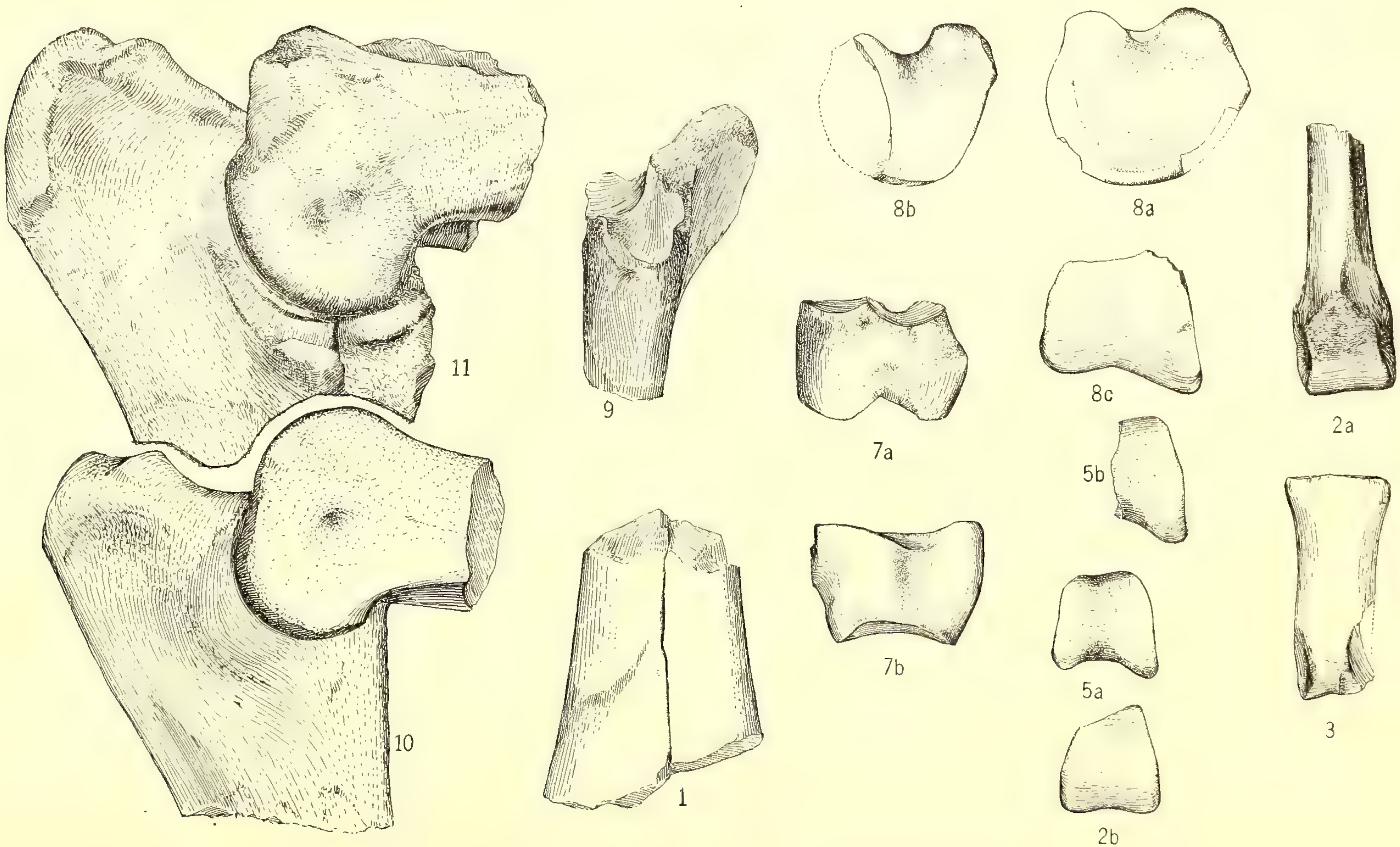
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5a
2b
2a
3

EXPLANATION OF PLATE 49

Equidae, Eden beds, California. All figs. × ⅔ except 1, 2 and 3, which are × ⅓.

Fig. 1. Tibia, no. 23478. × ⅓.

Fig. 2. Portion of astragalus, no. 23363. × ⅓.

Fig. 3. Navicular, no. 23364. × ⅓.

Fig. 4. Calcaneum, no. 23456. × ⅔.

Fig. 5. Psiform, no. 23362. × ⅔.

Fig. 6. Proximal portion of metacarpus, no. 23457, two views. × ⅔.

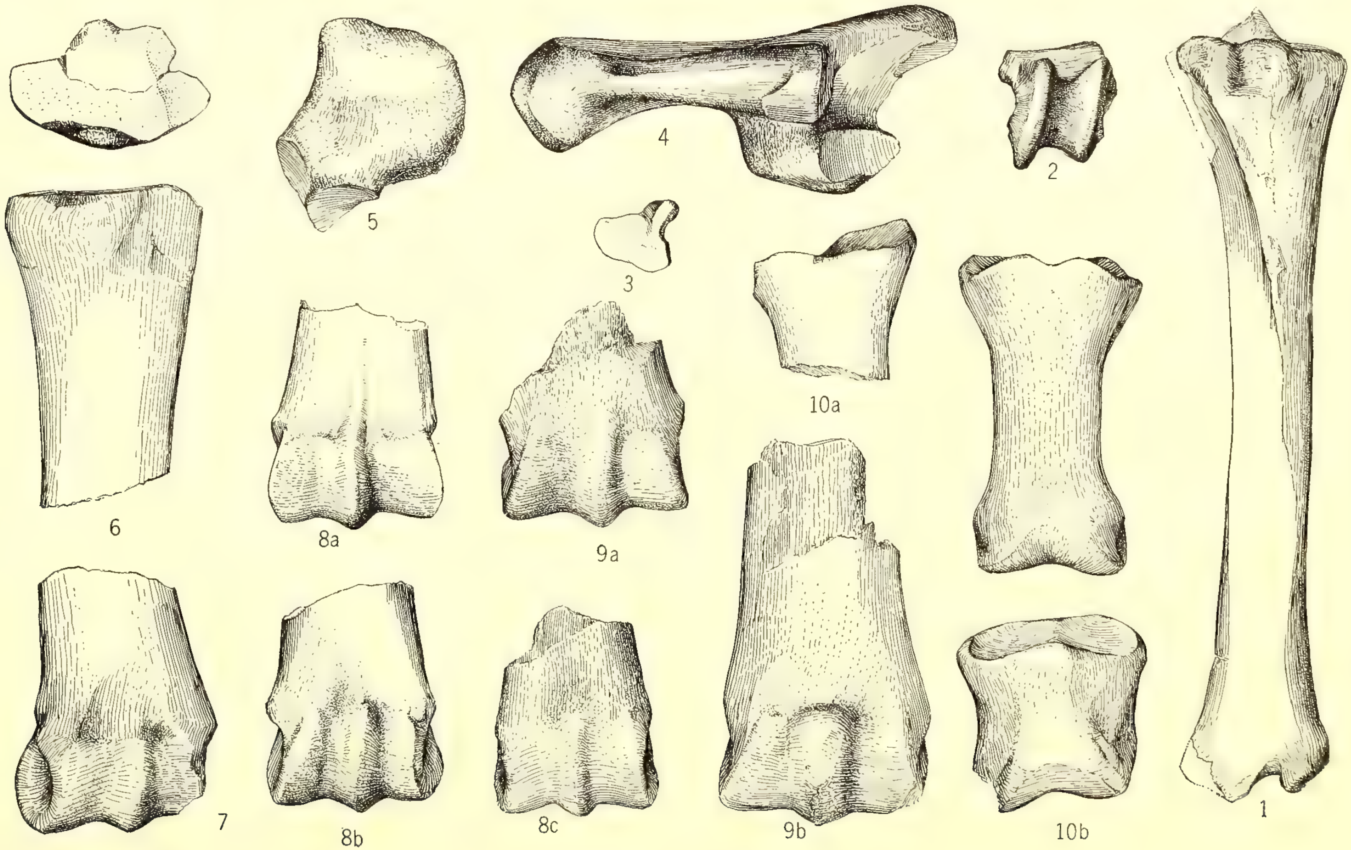
Fig. 7. Distal portion of medium-sized metapodial, no. 23454, superior aspect. × ⅔.

Fig. 8. Distal portion of small-sized metapodials: *a*, inferior aspect; *b*, superior aspect, no. 23355; *c*, superior aspect, no. 23357. × ⅔.

Fig. 9. Distal portions of larger metapodials: *a*, no. 23356; *b*, no. 23361, dorsal aspects. × ⅔.

Fig. 10. Phalanges. *a*, Proximal portion, no. 23366; *b*, first phalanx, no. 23367; and a much larger second phalanx, no. 23518. × ⅔.

All Univ. Calif. Coll. Vert. Pal.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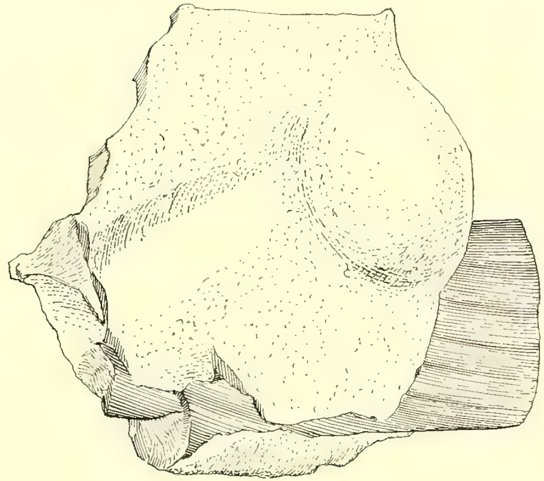
8b
8c
9b
10b

EXPLANATION OF PLATE 50

Trilophodon shepardi edensis n. subsp. Eden beds, California.

Figs. 1 and 2. Portions of premaxilliary and tusks of Eden type specimen, no. 24047, × ¼.



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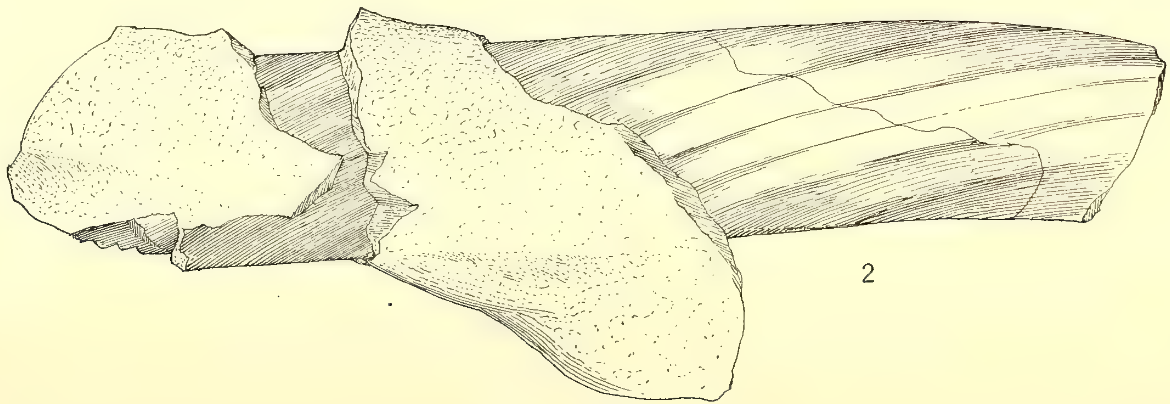

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BULLETIN OF THE DEPARTMENT OF
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Vol. 12, No. 6, pp. 425-430, plate 51 November 22, 1920

A MOUNTED SKELETON OF MYLODON HARLANI

BY
CHESTER STOCK

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY

O. P. Hay.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
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A MOUNTED SKELETON OF MYLODON HARLANI

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CONTENTS

INTRODUCTION

Skull and skeletal materials of the ground sloth *Mylodon* occur not uncommonly in Pleistocene deposits of North America, yet nowhere, with the single exception of Rancho La Brea, have remains of this genus been found in sufficient completeness to permit the satisfactory construction of a mounted individual. On the contrary, frequent occurrence and favorable preservation of remains of *Mylodon* and of related genera in Pleistocene beds of South America have furnished opportunity to prepare a number of mounts of these mammals. Studies based on the latter specimens, and especially the excellent description of *Mylodon robustus* by Sir Richard Owen, have made available a fund of knowledge concerning the Mylodontidae of South America that has remained, heretofore, unparalleled. Fortunately, however, recent studies of the large collection of edentate remains from the asphalt beds of Rancho La Brea have made possible the completion of a mount of the species *Mylodon harlani*, and an occasion presents itself, therefore, to secure information of the North American mylodont sloth as detailed as that which we have of the southern types.

This specimen of *Mylodon harlani* was prepared and is now on exhibition at the Museum of History, Science and Art, in Los Angeles. Permission to study the edentate collection and to use portions of it

for a mounted individual, in pursuance of a plan to monograph the ground sloth group from Rancho La Brea, was most generously granted by the late director of the Museum, Dr. Frank S. Daggett. The task of assembling the skeleton and preparing the mount has been admirably accomplished by Mr. J. W. Lytle, preparator at the Museum. The photograph was taken by Mr. L. E. Wyman, and permission to reproduce it has been kindly given by Mr. Howard Robertson, Acting Director.

CHARACTERS OF MYLODON HARLANI

Dermal ossicles present in skin.

Skull[1] with premaxillaries usually loosely joined, sometimes co-ossified, with maxillaries.

Dentition[1] $\frac{5\text{–}4}{4}, \frac{5\text{–}4}{4}$

Thyroid cartilage sometimes ossified.

Vertebral formula: C 7; T 16–15; lumbar-sacral 8–9; Ca 21.

Chevron bones articulate with caudal vertebrae. Anterior chevron consists of a right and a left piece which are not joined in median line. In middle portion of tail chevron bones are Y-shaped with haemal spines broadened anteroposteriorly.

Separate cervical rib sometimes present, articulating with seventh cervical vertebra. Fifteen pairs of body ribs in mounted specimen.

Seven sternal elements. Sternal ribs ossified.

Clavicle present.

Anterior limb heavy; scapula with coraco-scapular foramen and with complete coraco-acromial arch; humerus with no entepicondylar foramen. Manus similar to that of *Mylodon robustus*. Digits 4 and 5 greatly reduced.

Pelvis with greatly expanded ilia; pubic symphysis short.

Posterior limb massive; femur broad, very heavy, and lacking a third trochanter. Foreleg shortened. $\frac{\text{Length of tibia (T)}}{\text{Length of femur (F}=1)} = .45$ Pes[2] as in *Mylodon robustus;* weight of body supported by large calcaneum and outer side of metatarsal 5.

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[1] Stock, C., Skull and dentition of the mylodont sloths of Rancho La Brea, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 319–334, 1914; Further observations on the skull structure of mylodont sloths from Rancho La Brea, Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, pp. 165–178, 1917.

[2] Stock, C., Structure of the pes in Mylodon harlani, Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, pp. 267–286, 1917.

REMARKS

The mounted skeleton of *Mylodon harlani* shown in plate 51 presents an animal with elongate skull, short neck, short and heavy body, broad pelvic girdle, and with a stout tail. The limbs are particularly heavy. The cumbrous weight of the body and the peculiar form of the posterior foot suggest a mammal with slow and labored movement. The animal apparently fed upon grass and small shrubs, and it may have used the well developed claws of the fore feet in digging for and uncovering roots. Undoubtedly the anterior extremities were formidable weapons of defense against attacks of large predaceous mammals, while the skin with dermal armor of ossicles gave added protection. It is presumed that *Mylodon* lived in stretches of open country in preference to regions supporting a heavy growth of timber.

Mylodon harlani was apparently an important member of the Pleistocene fauna of western North America during the time of accumulation of the asphalt beds and the vertebrate remains at Rancho La Brea, for it is one of the group of large mammals represented by many individuals in the assemblage of forms known from these deposits.

The accompanying illustration (pl. 51) of the mounted specimen is reproduced only as preliminary to further study of the skeleton of *Mylodon harlani.* Critical restudy of the posterior extremities with special reference to posture of limbs and of feet may necessitate changes in the mount that will impart a somewhat different appearance to the specimen. A more detailed discussion of *Mylodon harlani* will be presented in the final report on the edentates from Rancho La Brea now in course of completion.

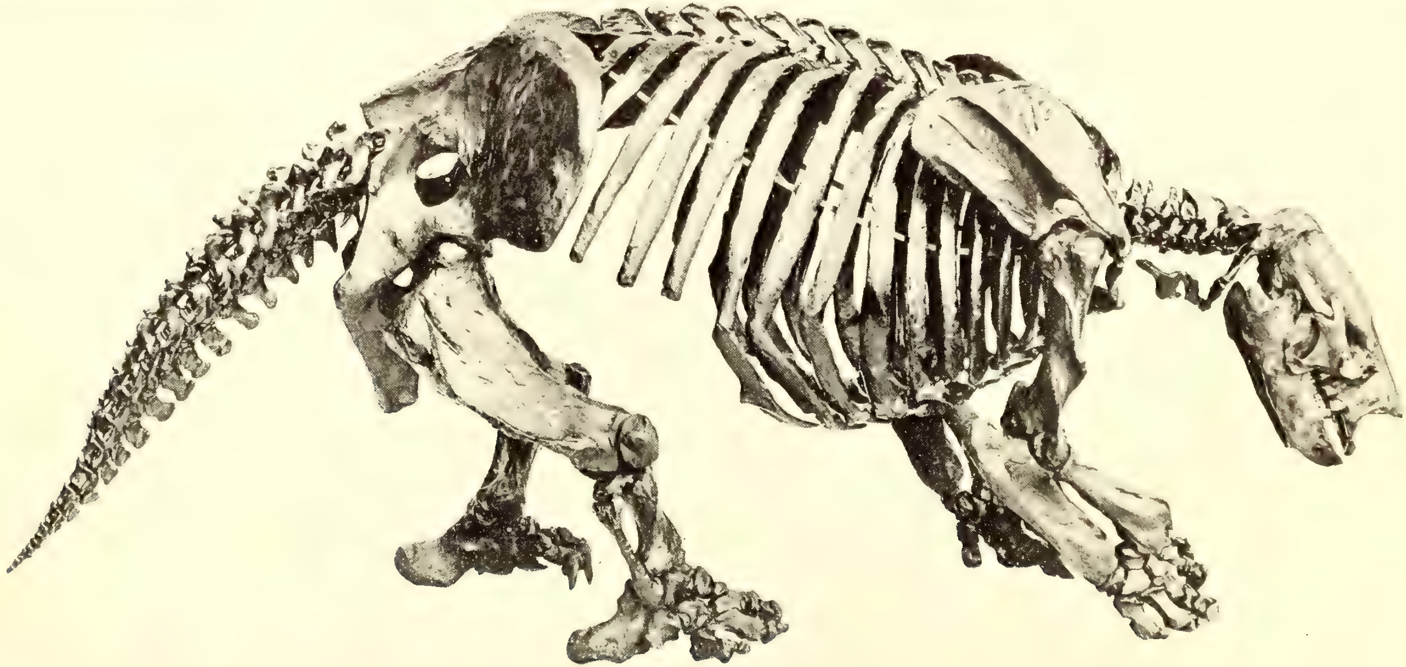
MEASUREMENTS

Length from anterior end of skull to end of tail, measured on horizontal line along base		279 cm.
Length of neck, measured from anterior end of atlas to neural spine of first thoracic vertebra		29.4
Length from neural spine of first thoracic vertebra to anterior end of neural spine of sacrum		103.3
Length of sacrum		49
Length of tail measured from posterior end of sacrum to end of last caudal vertebra		118
Height of posterior end of skull above base	*v*	78.5
Greatest height of superior border of scapula (left limb) above base	*v*	111.5
Greatest height of superior border of left ilium above base	*v*	122
Height of pubic symphysis above base	*v*	44.5
Greatest transverse diameter of body measured across outer sides of tenth ribs		98
Width across lateral borders of ilia		108
Width of manus, from internal or anterior border of metacarpal 1 to posterior or lateral border of metacarpal 5		18
Length of pes from anterior end of ungual, digit 3, to posterior end of calcaneum		44

v, measurement taken vertical to base.

EXPLANATION OF PLATE 51

Mylodon harlani Owen. Mounted skeleton on exhibition at the Museum of History, Science and Art, Los Angeles, California. View of right side, $\times \frac{1}{15}$. Rancho La Brea beds, California. Photograph by L. E. Wyman.



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THE MOBILITY OF THE COAST RANGES OF CALIFORNIA

AN EXPLOITATION OF THE ELASTIC REBOUND THEORY

BY
ANDREW C. LAWSON

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CONTENTS

INTRODUCTION

In his masterly discussion of the mechanics of the California earthquake of 1906 Reid[1] makes it clear that the forces which moved the earth's crust in the region affected were applied to its under side, that these forces generated a strain in the elastic rocks of the crust, and that, at the time of relief from strain by the fault slip, the sudden movement of the ground was an elastic rebound. This conception of elastic rebound on rupture planes in the crust on which strain is suddenly relieved, was subsequently generalized by Reid,[2] and is the most satisfactory explanation of earthquakes that has been formulated.

The notion that the stresses which generated the strain in the crust were applied to the lower side of the mobile region is a logical necessity which may be freely accepted, but the application of those stresses, particularly the direction of their operation, is left by Reid undecided. He points out that the phenomena observed may be explained on one or the other of two hypotheses:

(1) A shearing strain generated by two currents of the subcrustal region flowing parallel to the fault in opposite directions and dragging the overlying crust with them, so as to produce a slow differential displacement of the sides of the zone of maximum shear.

(2) A single current flowing northerly, parallel to the fault, developing a zone of shear in the riding crust between the mobile region to the west and the stationary region to the east of the fault.

Reid's discussion of these two possibilities applies particularly to the phenomena observed to the north of the Golden Gate. But his treatment of the problem is general and apparently intended to be comprehensive of the whole field of disturbance; and he makes only incidental reference to the results of the geodetic survey in the region to the south of the Golden Gate, some of which appear to be anomalous.

In the Report of the State Earthquake Investigation Commission I made the following comment[3] on this southern portion of the field:

> In the region about Monterey Bay the most interesting fact brought out by the geodetic resurvey is that the combined effect of the earlier movement and that of 1906 is a southerly migration of the earth's crust on both sides of the

[1] Report of the State Earthquake Investigation Commission, vol. II, Carnegie Institution, 1910.

[2] The elastic rebound theory of earthquakes, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, no. 19, 1911.

[3] Vol. I, p. 151.

San Andreas rift. It is probable from direct observations of relative displacement along the fault-trace in 1906 that the southwesterly block moved northwest as far as the rupture extended. If this be accepted, then the southerly net movement on the west side of the south end of the fault is due to the predominance of an earlier southerly movement. This agrees with the positive and certain earlier displacement of Loma Prieta. Accepting the southerly character of this earlier movement as certain, there is forced upon us the remarkable fact that the direction of displacement in the region about Monterey Bay is the reverse of that of the earlier movement for the region north of San Francisco Bay. This means that the earlier movement was distensive in character, displacing the territory to the north of San Francisco Bay northerly, and that to the south southerly while the vicinity of the Bay itself was relatively neutral. It appears, moreover, that the southerly displacement was differentially diffused, since the amount of displacement of the south side of Monterey Bay was notably greater than that of the north side, resulting in a widening of the Bay by about 10 feet.

Similarly the distance between Tamalpais and Black Mountain, both on the same side of the San Andreas rift, has been increased by a like amount. The significance of this general distension involved in the reversal of the direction of displacement to the north and south of San Francisco Bay, and of the differential character of this distension, without known rupture, at Monterey Bay and San Francisco Bay, cannot at present be stated.

In the interval between the issue of volume I of the Report of the State Earthquake Investigation Commission in 1908 and that of volume II, containing Reid's discussion, Rothpletz[4] published a paper entitled "Über die Ursachen des Kalifornischen Erdbebens von 1906," in which he discussed the data contained in volume I of the Earthquake report, and advanced a theory explanatory of the cause of the disturbance.

In this paper Rothpletz considers that the results of the geodetic survey, set forth by Hayford and Baldwin, establish the fact of distension of the region in which San Francisco Bay lies; and his account of the mechanics of this distension is his theory of the cause of the earthquake. He discusses first a distension which affected the region prior to 1906, presumably in 1868, at the time of the great earthquake of that year, and considers three hypotheses: (1) Tangential pressure, or expansion of a compressed region by reason of the diminution of pressure. (2) Expansion due to increase of temperature. (3) Injection of dykes of molten magma. He rejects the first two of these hypotheses and adopts the third. He holds that the apparent distension was due to the injection into the crust of a group of dykes transverse to the direction of maximum movement, that the aggregate width of the dykes was 7.2 meters, and that the injection was effected suddenly,

[4] Sitzungsberichte, Kön. Bayer. Akad. d. Wissen., München, Math.-phys. Klasse, 1910, 8; Abhandlungen, 1910.

probably at the time of the earthquake of 1868, of which it was the immediate cause. He then takes up the earthquake of 1906 and the slip on the San Andreas fault. These are similarly explained by sudden injection of molten magma, with this difference, that in 1906 there was a greater aggregate of dyke material injected on the west side of the San Andreas fault than on the east side, thus accounting for the differential horizontal displacement on the fault. Speaking of this differential displacement, he says:

> Diese Feststellung ist eines der wichtigsten Ergebnisse der geodätischen Aufnahmen, denn sie beweist uns, dass wir keine gewöhnliche Spaltenverschiebung vor uns haben, bei denen die Verkrümmung gerade in entgegengesetzter Richtung eintritt, wo sie dann als Schleppung bezeichnet wird und uns als eine Riebungshemmung leicht verständlich ist. Wir müssen für ihre Erklärung nach anderen Ursachen suchen und Lawson (S. 150) findet sie in der Annahme, dass durch die vorausgegangenen, bereits besprochenen Expansionsbewegungen der Boden in eine elastische Spannung geraten war, durch welche die einzelnen Punkte der Oberfläche in eine Zwangslage kamen, aus der sich zu befreien und in ihre frühere Position zurückzukehren sie das Streben hatten. Sobald nun die Spalte aufriss, war es den Punkten unmittelbar zu beiden Seiten leichter, ihre ehemalige Stelle wieder zu erlangen als, den entfernteren, und deshalb war die Bewegung an der Spalte eine grössere als weiter ab.
>
> Diese Erklärung müsste zur Voraussetzung haben, dass die ursprungliche Lage der Punkte vor den die Spannung erzeugenden älteren Bewegungen auf der Westseite der Spalte weiter im Süden, auf der Ostseite weiter im Norden war. Das trifft aber nicht zu. Denn die älteren Bewegungen waren alle im Norden nach Norden und im Süden nach Süden gerichtet gewesen. Ich kann mich deshalb dieser Deutung des Vorganges nicht anschliessen.

He thus definitely rejects the notion of elastic rebound that I advanced in volume I of the Earthquake report.

At a later date Mr. H. O. Wood became impressed with the reality of the apparent distension and sought to explain it. In a paper "On a possible causal mechanism for heave fault slipping in the California Coast Range region,"[5] he ascribes the distension to deep isostatic flow both northwest and southeast from the vicinity of San Francisco Bay, on the assumption that the Coast Ranges are being dragged down by the growing load in the Great Valley of California, San Francisco Bay, and on the sea floor off the coast. He accepts the elastic rebound explanation of the fault, and his purpose is to account not only for the apparent distension, but also for the strain, the sudden relief of which caused the displacement of the year 1906.

The foregoing are the only important contributions to the solution of the problem of the earthquake of 1906 that have come to my attention. It is the purpose of the present paper to further exploit the

---

[5] Bull. Seism. Soc. Am., vol. V, pp. 214–229, 1915.

theory of elastic rebound in its application to the movements of the region traversed by the San Andreas fault, and particularly Reid's second hypothesis, in a modified form, of a single northerly subcrustal flow, dragging the crust with it, and so developing in the latter a state of strain, from which it is relieved from time to time by rupture, or by slipping on old rupture planes.

The geodetic data upon which my discussion rests are all to be found in the paper by Hayford and Baldwin[6] or in a later report of the Coast and Geodetic Survey,[7] which supplies a convenient tabulation of the positions of many points as determined by surveys of different dates.

Chronologically these surveys fall into three classes: (1) those made before 1868, (2) those made between 1868 and 1906, (3) those made in 1906–1907 after the earthquake; and they may be referred to as surveys I, II, and III respectively.

The fact that there was a sudden displacement by slip on the San Andreas fault in 1906, seems to have inclined Hayford and Baldwin to the view that displacements which were discovered to have occurred between surveys I and II were effected by a similarly sudden movement in 1868, at the time of the earthquake of that year. This assumption is made by them, however, as a matter of convenience in discussion, and not because there is any evidence to establish the fact. The assumption is probably justified for part of the region south of the Golden Gate, as I shall point out in the sequel. But as there is no evidence whatsoever for a sudden displacement of the region north of the Golden Gate in 1868, and as the observed facts in that part of the field can be better explained without such an assumption, I shall proceed on the simpler hypothesis that there was no appreciable sudden shifting of positions to the north of the Golden Gate in 1868 such as occurred in 1906.

BASIS OF HYPOTHESIS OF CAUSAL STRESS

The reasons for adopting Reid's second hypothesis that the fundamental cause of strain throughout the region is a stress applied to the lower side of the earth's crust by a *single* current flowing northerly, are:

1. In the region north of the Golden Gate all the stations which were determined in position by surveys I and II of the Geodetic

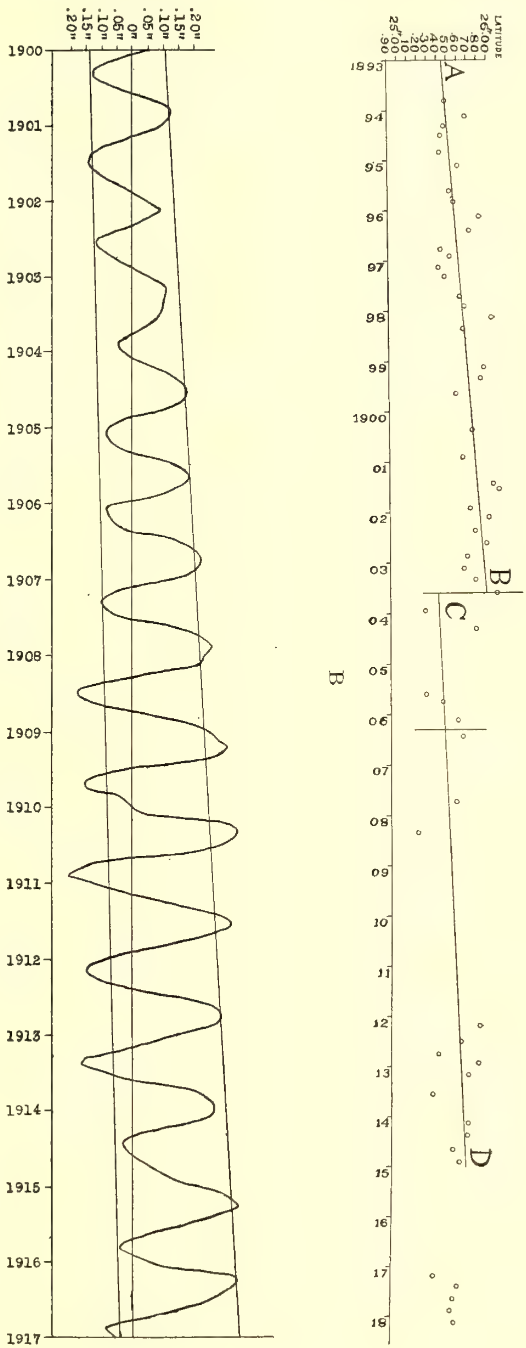
[6] Earthquake Report, Geodetic measurements of earth movements, pp. 115–145.

[7] Report for 1910, Append. 5, Triangulation in California, pt. II, by C. R. Duvall and A. L. Baldwin, Washington, 1911.

Survey show a northerly movement in the interval; and the evidence of this is more abundant on the east side of the San Andreas fault than on the west side. This northerly movement is, in accordance with the rebound theory, interpreted as an expression of strain. The mean rate of northerly strain creep of the region for the period between surveys I and II based on the observations at Tamalpais, Chaparral, Ross Mountain, and Farallon is .052 meters per year.

2. The results of observations at Ukiah undertaken since 1900 to establish the variation of latitude, show that, besides the rhythmical variation due to the movement of the pole of rotation around the pole of figure of the earth, there is a northerly migration of the station itself. I am not aware that this fact has been recognized by the astronomers; but certain published results clearly show this to be a fact. In a paper by Sir F. W. Dyson[8] on ''The Variation of Latitude'' there are published curves showing the variation of latitude, 1900–1917, at Ukiah and other stations. The curve for Ukiah is here reproduced, on a different scale, in figure 1, A. It shows the periodic departure of the station from its mean latitude, or mean position of the pole, as determined from observations at several stations around the earth established for the purpose. If we consider the peaks of the curve on either side of the zero line, it is apparent that there is a pronounced tendency for them to migrate northerly in the interval covered by the curve. I have endeavored to bring this out by regarding the peaks on each side as falling into a curve and smoothing out the curve as a straight line. Owing to the variation of amplitude of the swing of the pole some of the peaks depart somewhat from the sloping lines that I have drawn, but this departure is more or less symmetrical on both sides of the zero line and is clearly due to a periodicity in the amplitude. The sloping lines will I think be conceded to be a fair expression of what appears to be a regular northerly migration of the station at Ukiah. The upward slope of the upper line, embracing the peaks of the northerly departure from the mean, is more pronounced than the lower line embracing the peaks of southerly departure. Taking these two lines as significant of a northerly creep of the region and basing my figures on the mean of the two sloping lines, I find that Ukiah is creeping northerly at the rate of about .29 meters per year. In arriving at this figure it is to be noted that, since the mean position of the pole represented by the zero line is based upon observations at all the stations including Ukiah, the zero line adopted diverges

[8] Monthly Notices of the Royal Astronomical Society, vol. 78, no. 7, May, 1918.



A

B

Fig. 1, A. Curve of variation of latitude of Ukiah station of the International Latitude Service, showing the northerly migration of the station from 1900 to 1917. After Dyson.

Fig. 1, B. Determinations of latitude of Lick Observatory, from 1893 to 1918, showing a northerly migration of the station, based on the observations of Astronomer R. H. Tucker.

northerly from the true zero line, and the rate of creep inferred from the curve, .29 meters per year, is in reality somewhat less than the true rate. For, if Ukiah be moving northerly, the increase of latitude due to this cause should not enter into the determination of the mean position of the pole, that is the position of the zero line in relation to the curve.

3. Meridian Circle observations have been maintained at Lick Observatory since 1893 by Astronomer R. H. Tucker, who has kindly supplied me with the following memorandum of the values for the latitude of the station. The results are based on observations both on circumpolar and zenith stars for an average of sixty-eight nights per year during the period from 1893 to 1918, except for the interval

Average Quarterly Values for the Latitude of Lick Observatory Based on Meridian Circle Observations by Astronomer R. H. Tucker from 1893 to 1918

Epoch	Latitude	Epoch	Latitude
1893.82	37° 20′ 25″.48	1902.62	37° 20′ 26″.87
1894.12	.69	.88	.68
.33	.47	1903.12	.65
.51	.44	.35	.76
.83	.43	.60	.88
1895.11	.61	.92	.25
.33	.57	1904.11	.48
.63	.52	.30	.76
.83	.56	1905.59	.26
1896.11	.82	.77	.42
.40	.72	1906.11	.58
.67	.43	.45	.63
.91	.52	1907.75	.56
1897.13	.41	1908.33	.18
.31	.47	1912.18	.79
.72	.62	.51	.60
.92	.67	.75	.38
1898.15	.94	.92	.78
.36	.65	1913.16	.68
.83	.77	.53	.32
1899.12	.86	1914.14	.68
.32	.82	.37	.67
.63	.58	.63	.52
1900.38	.73	.90	.59
.89	.64	1917.18	.34
1901.46	.94	.39	.58
.57	6.03	.62	.54
.92	.71	.88	.51
1902.13	.90	1918.11	.55
.37	.76		

1908 to 1912, when Mr. Tucker was in South America. The values tabulated are the averages by quarter years, as near as possible, and the number of nights in each quarter during which observations were made averages seventeen. The results have been corrected for the revised refractions adopted at Lick Observatory and for the variation of latitude.

I have taken these values and plotted them on coördinates in figure 1, B. It is apparent from an inspection of the figure that, notwithstanding the variations in the values, there is in general a fairly steady increase in the latitude from 1893 to 1903. This increase is expressed in the mean line *A–B*. It amounts to 0″.4 in ten years, or at the rate of 0″.04 or 1.24 meters per year.

Between 1903.60 and 1903.92 there is an exceptionally large drop of 0″.63 in the value for the latitude. In this interval occurred the earthquake of August 2, 1903, which was rather severe at the Lick Observatory. It seems not improbable that the rather large drop in the value of latitude may be due to a shift of the ground at the time of this earthquake. The values for latitude since 1903.60 clearly fall into a grouping distinct from the grouping of the values for the period preceding that date. The mean expression for the values, as indicated by the line *C–D*, is, however, not so satisfactory as the line *A–B*, owing largely to the interval of no observations from 1908 to 1912. This line rises from 1903 to 1915, but at a less rapid rate than the rise of the line *A–B*. The rate of increase of the value for latitude for this period is 0″.022 or .70 meters per year. Beyond 1915 the data are insufficient for the determination of a mean position. It is interesting to note that there is no indication of sudden change of position at the time of the slip on the San Andreas fault in 1906.

The rate of increase of latitude of Lick Observatory on either side of 1903.6 is much greater than that at Ukiah, and there may be doubt as to the true value of the rate, owing to the fact that the lines *A–B* and *C–D* each represent the mean position of a series of points which depart notably and irregularly from the adopted mean. There can, however, be no doubt as to the general significance of the observations, particularly between 1893 and 1903. They accord with those of Ukiah in pointing to a northerly creep of the region. The increase of latitude both at Ukiah and Mount Hamilton, taken together with the legitimate deductions that may be made, in the light of the rebound theory, from the results of the geodetic surveys in the intervening territory, seems to establish the fact of a northerly creep of the Middle Coast Ranges.

4. The movement of 1868 can be explained consistently on the hypothesis of a single northerly current; and the supposed distension of the region which formed the basis of the discussions of Rothpletz and Wood becomes unreal.

POSSIBILITIES OF TRANSVERSE SHIFT

There being by assumption no sudden movement in 1868, the displacement between surveys I and II in the region north of the Golden Gate must be the expression of strain creep; and, the dates being known, we have the rate of strain creep. Thus, Tamalpais between 1854 and 1882 was displaced 1.64 meters in the direction 168° by strain creep the rate of which was therefore apparently $\frac{1.64}{28} = .058$ meters per year. Similarly Chaparral was displaced 1.83 meters in the direction 173° between 1856 and 1891, which is at the rate of .052 meters per year. For Ross Mountain the rate of strain creep is in the same way found to be .053 meters per year in the direction 182°. Using this rate we may determine the position of geodetic stations just prior to the earthquake of 1906, and so arrive at the true amount and direction of displacement by slip on the San Andreas fault in that year. This method, however, involves the further assumption that the straight line connecting the positions of a given station, as determined by surveys I and II, is the direction of strain creep. But this is not necessarily the case, as will appear from the following considerations. The stations we are concerned with are all in a region of accumulating strain, and the strain was relieved by a slip on the San Andreas fault. Now faults are things with which geologists are familiar; and in many of the exposures of faults which they have occasion to examine in mines, etc., the phenomena known as ''drag'' are well displayed. The term drag is, however, comprehensive of two distinct phenomena, although the distinction is not always kept clearly in mind. These are: (1) the bending of the rocks in the zone of shear prior to the slip on the fault, and (2) the smearing out in the fault plane of the products of attrition at the time of the slip on the fault. Both effects are of importance in the study of the San Andreas fault and the movements connected therewith. The bending in the shear zone of a fault is best exemplified in stratified or laminated rocks, particularly where the strata are thin and strong layers alternate with weak. It is, as commonly observed, a plastic deformation; and the structure

imposed upon the rocks in the development of the shear zone remains after the general elastic strain has been relieved by slip on the fault. The development of this bending shear involves a shortening of distances measured transverse to the shear zone, as may be appreciated by an inspection of the diagrams in figure 2. If *a* and *b* be the boundaries of a shear zone in three stages of its development, I, II, and III, it is apparent that *a* and *b* are closer together in the later or more acute stages of the shear than in the earlier. If the shear zone were 10 meters wide at the initial stage it might easily be reduced to

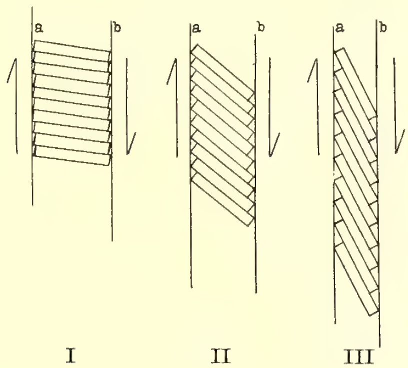


Fig. 2

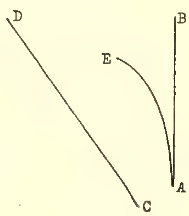


Fig. 3

Fig. 2. Three stages of bending shear to illustrate transverse shortening.

Fig. 3. Path of a point under combined strain creep and transverse shortening.

8 meters or less at a later stage, just prior to rupture. Such shortening would proceed at an increasingly rapid rate as the shear developed, and would involve a creep of the region towards the fault on each side of it. If, for example, we consider the case of the San Andreas fault and assume that it traverses such a shear zone as I have described, the primary strain creep to which the shear is due would be modified in direction by combining with the secondary creep due to shortening transverse to the shear zone during its development. Thus in the diagram, figure 3, if *AB* be the direction of primary strain creep and *CD* the azimuth of the fault, then, as a point to the east of the fault moved from *A* toward *B* it would be deflected to the left by the secondary creep due to shortening; and the point in arriving at *E* from *A* would have followed the curved path *AE*.

But while I have assumed, for the purpose of elucidating the principle, that the slip on the San Andreas fault was preceded by the

development of bending shear, conducive to shortening in the direction normal to the fault, it is very improbable that the highly elastic granite which underlies the region would lend itself to such a bending shear as is commonly developed in more plastic rocks. There must doubtless have been developed an elastic deformation somewhat analogous to the bending in plastic rocks; but, so long as this kept within the elastic limit of the rock, the shortening would practically be inappreciable. We may therefore conclude that there was no shortening transverse to the shear zone of the San Andreas rift due to bending, as exemplified in thinly stratified rocks in similar situations, or due to elastic deformation of the granite. There is, however, another case to be considered. The San Andreas fault is an old fault, on which slips have repeatedly occurred. At each slip some of the granite on each side of the fault was doubtless crushed and partially pulverized, thus developing a zone of fault breccia and gouge. This zone might easily be 100 meters or more in width. Such a zone of breccia and gouge was observed by the engineers who drove the tunnel of the Los Angeles aqueduct through granite, across the San Andreas fault, near Lake Elizabeth. Such a breccia zone once developed would afford opportunity for plastic shearing for every subsequent renewal of strain; and such plastic shearing might involve a very appreciable shortening of distances measured transverse to the fault. It is highly probable that a wide breccia zone exists on the San Andreas fault for its entire length. Thus while there is no probability of shortening in this case due to bending, whether plastic or elastic, there is a possibility that such a shortening might occur by plastic shearing of the breccia zone. This possibility, however, would be realized in fact only if the shear were a bending shear such as is exemplified in thinly stratified rocks. But the shortening thus effected transverse to a long fault, such as the San Andreas fault, implies the accommodation elsewhere of a very large volume of rock matter, since the total content of the breccia zone cannot be diminished. Thus a shortening of a meter on a fault breccia 100 km. in length and 10 km. deep would necessitate the accommodation, outside of the shortened region, of a billion cubic meters of rock. It is difficult to imagine any way in which such accommodation could be effected otherwise than by extrusion, and there is no suggestion of any such extrusion in fact. It seems clear, therefore, that the shear on the breccia zone of the San Andreas fault could not have been a bending shear and could only have been a slicing shear such as is illustrated in the diagram, figure 4. Here all lines transverse to the

zone are sliced into short segments and moved differentially parallel to themselves; there is no diminution of the width of the zone and therefore no creep of the region on either side towards the fault. The general result of the discussion is that it is highly improbable that there is any appreciable transverse creep or shortening due to shear. The reason for examining into the matter is that there is, as will appear later, a suggestion of a transverse movement in the region traversed by the San Andreas fault, and it seemed necessary to exhaust this possibility.

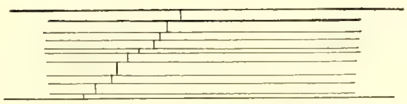


Fig. 4. Shearing by slicing without transverse shortening.

LONGITUDINAL AND TRANSVERSE STRAIN

The subcrustal flow which, by carrying the crust with it, induces strain in the latter, must be local. Beyond the region affected, in the direction of the stress, there must be a stable region against which the mobile region is forced so as to produce a condition of compressive strain. Similarly, in the case before us, for sections transverse to the direction of stress the latter must be differential, otherwise there could not be induced the particular kind of strain which would be relieved by a vertical shear and horizontal slip on a vertical fault. If the stress, and therefore the strain, were uniformly distributed in the east-west direction normal to the stress, the strained condition on reaching the limit could be relieved only by slip on an inclined fault with east-west strike, combined with shearing on the borders of the region affected by the stress. Since, then, there are two modes of relief for the strain generated under the hypothesis of a subcrustal current, it will be convenient to recognize the two kinds of strain by separate designations. I shall, therefore, call the strain which would be relieved by slip on a low dipping transverse fault the longitudinal strain, and that which would be relieved by slip on a vertical fault the transverse strain. The San Andreas fault is, at least near the surface, vertical, and its strike is about 144°; that is, it intersects the northerly direction of strain creep or of stress at an angle of about 30°. At the

time of the slip in 1906 the southwest side advanced and the northeast side sprang back. It is highly probable, as Reid has pointed out, that the fault traverses a shear zone, which was an antecedent condition to the slip. But the shear zone could not have developed, nor the slip have happened unless the strain had been greater to the west than to the east. It is probable that somewhere to the east of the fault the strain dies out. The locus of zero strain due to subcrustal flow is, however, unknown. We do not even know positively whether this locus is parallel to the San Andreas fault or not. It seems probable, however, that it is not, but that it is more nearly parallel to the observed direction of strain creep. It follows from the foregoing that the rate of strain creep must increase from nothing at the locus of zero strain to the rate inferred from the geodetic observations near the fault; and that this rate is greater on the west side of the fault than on the east side. Beyond the fault an unknown distance the rate doubtless diminishes again to zero, at the western border of the subcrustal current. For points to the west of the easterly zero locus the rates of strain creep, if plotted as ordinates from a straight line, would doubtless terminate on a curve. But the curve is probably very flat. The rates of creep inferred for Chaparral and Ross Mountain indicate that the curve is nearly a straight line, and that the zero locus must be far to the east. In so far as the curve approximates a straight line the rate of creep is proportional to the distance from the zero locus. In so far as the zero locus is remote the difference in rate for points a few kilometers on either side of the fault is small. Now all of the data that we have for the rate of creep of the region in the vicinity of the fault is derived from stations on the east side of it. In the discussion which follows the rates thus obtained are assumed to hold for the stations on both sides of the fault for which we have the measure of movement. This assumption is mathematically incorrect; but it appears to be the best that can be done under the circumstances. The error involved in the assumption is probably small and does not invalidate the general nature of the results arrived at, the purpose of the discussion being not to arrive at precise quantities, but merely to interpret the process of earth movement in the light of the rebound theory.

It may be further observed from the general point of view, before going into details, that the failure of slipping on the San Andreas fault to relieve the longitudinal strain leaves us in the expectation of that relief by other movements. These movements would affect the whole

region on both sides of the San Andreas fault, and are not necessarily synchronous with the movements on that fault. As will appear from the discussion which follows, the earthquake of 1868 was probably due to sudden relief of the longitudinal strain in the region south of the Golden Gate, on a low dipping, deep fault, the emergence of which at the surface has not yet been observed.

REGION NORTH OF THE GOLDEN GATE

I shall now review briefly the data for various geodetic stations the positions of which were determined at various dates, and interpret those data in the light of the elastic rebound theory.

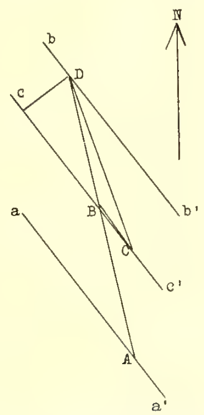


Fig. 5. Mount Tamalpais moved 3.04 meters from *A* to *D* between 1854 and 1906 by strain creep, and 1.97 meters from *D* to *C* in 1906 by rebound.

Tamalpais.—We may take first the case of Mount Tamalpais. The positions of this point were determined by surveys I, II, and III. In figure 5, let *A, B, C* represent the positions in 1854, 1882, and 1906 respectively. Between 1854 and 1882, a period of twenty-eight years, the point migrated 1.64 meters presumably in a straight line, the azimuth of which is 168°. There is no reason to suppose that the movement ceased abruptly in 1882; and we may safely assume that it continued at the same rate in the same direction up to 1906*a*,[9] as the manifestation of the accumulating strain which was relieved in that year at the time of the earthquake. The rate of strain creep from

[9] Throughout this paper 1906*a* means 1906 prior to the earthquake and 1906*p* means 1906 after the earthquake. Similarly 1868*a* and 1868*p* mean 1868 before and after the earthquake respectively.

1854 to 1882 was .058 meters per year. Applying this rate to the interval 1882–1906*a* we find that Tamalpais must have arrived at *D*, a distance of 3.04 meters from *A* in 1906*a*. Then, at the time of the slip on the San Andreas fault, the strain being thereby relieved, Tamalpais sprang back suddenly to the point *C*, where it was found by survey III after the earthquake, the measure of the rebound being 1.97 meters in azimuth 341°.

The path of the station on its rebound from *D* was, however, parallel to the San Andreas fault upon which the slip occurred. It therefore moved along the line *bb′*, and could not have arrived at *C* by that movement. There are two possible explanations of this incongruity: (1) The San Andreas fault moved parallel to itself to the southwest an amount equal to the normal distance from *C* to *bb′*, which is .58 meters, or (2) the position of the station in 1906*p* was on the line *bb′* and not at the point *C*, as the Geodetic Survey determined. Let us consider these two possibilities in turn. First let us assume that the trace of a fault having a strike of 144° passes through the Tamalpais geodetic station. This fault trace in 1854 would have had the position *aa′*, in 1906*a* the position *bb′*, and in 1906*p* the position *cc′*. That is to say, if there had been such a fault, it would have participated in the slow strain creep between 1854 and 1906*a* and on April 18, 1906, it would have sprung back suddenly to the position *cc′* with the rest of the country. Thus the station by rebound along the line *bb′* parallel to the direction of slip, and a coincident shift of the line *bb′* itself could have arrived at the point *C*, where it was found by the Geodetic Survey. Such a shift would have involved the same shift of the San Andreas fault, and this may be imagined to have been effected either by a slip on a deep, east-west fault, relieving the longitudinal strain, or by a sudden transfer of a transverse strain to the southwest of the fault. Second, let us assume, as an alternative to the foregoing, that the controlling base line Diablo–Mocho was not immobile in the interval between surveys II and III, but that it moved northerly parallel to itself, or without change of azimuth, by operation of the strain creep which I have recognized as a necessity of the elastic rebound theory in the more western parts of the field. A creep of a meter in azimuth 180° between surveys I and II of this controlling base would have the effect of locating *C* on the line *bb′* and so removing all incongruity.

Chaparral.—Let us next consider the record of Chaparral, which also was located by the surveys I, II, and III. In figure 6, *A, B,* and *C*

represent the positions of this station in 1856, 1891, and 1906*p*. In the interval from 1856 to 1891 the point moved 1.83 meters in the direction 173°. This is at the rate of .052 meters per year, practically identical with the rate for Tamalpais. Again there is no reason to suppose that the movement stopped abruptly at *B* in 1891. It doubtless continued in the same direction at the same rate till 1906*a*, when the strain generated reached the limit. Applying the rate of strain creep to the interval 1891–1906, we find that the station must have moved an additional .780 meters and reached the position *D*. On April 18, 1906, the station moved back by the rebound to *C*, a distance of 2.06 meters in the direction 337°.

But again, as in the case of Tamalpais, the path of the station in its rebound from *D* must have been parallel to the near-by San Andreas fault, the azimuth of which is indicated in the diagram by the line bb'; and by rebound from *D* along the line bb' the station could never have arrived at *C*. The same two possible explanations obtain here as in the case of Tamalpais. As Chaparral moved northerly under strain creep the near-by San Andreas fault must have moved in the same direction at the same rate, keeping a constant azimuth. If aa' be the position of a line parallel to the fault in 1854 it would have moved to bb' in 1906*a*; and at the time of the earthquake it might have sprung back to the position cc', either by a slip on a deep fault, or by a transfer of strain to the southwest side of the fault. Failing this the only other available explanation is that *C* was located about a meter too far south by reason of the assumption of immobility of the Diablo–Mocho base. Whichever explanation be the true one, the apparent transverse shift measured normal to the fault is here .57 meters.

Ross Mountain.—Ross Mountain was similarly located by the surveys I, II, and III, and a similar analysis and interpretation may be made of its movements from 1856 to 1906*p*. The rate of strain creep here was .053 meters per year and its direction was 182°; but as the station is relatively remote from the San Andreas fault, the measure of the rebound, in this case a doubtful figure, was only somewhat more than half that of Tamalpais and Chaparral. The apparent transverse shift measured normal to the azimuth of the San Andreas fault is .35 meters.

Sonoma.—Sonoma, 34 km. distant from the San Andreas fault, to the east, was located in 1856 and again in 1906*p*, but not in the interval between. The displacement between these dates was 1.24+ meters in

the direction 183°, and is certain. If, as Hayford and Baldwin[10] are inclined to think, "Sonoma Mountain did not move much, if any," in 1906, then 1.24+ meters is the measure of the strain creep in fifty years, and the rate of strain creep is .025+ meters per year. In the absence of any determination of position between 1856 and 1906*p* Sonoma Mountain is of interest chiefly in establishing the fact that, if there were no sudden movement in 1906, then the direction of strain creep was 183°; and if a slight displacement did occur in 1906 the direction of strain creep was somewhat more westerly than 183°.

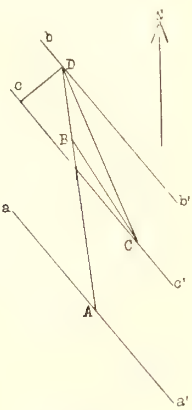


Fig. 6

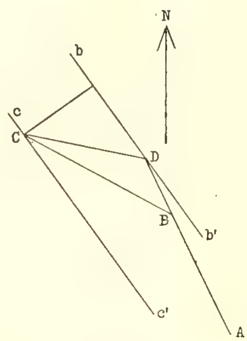


Fig. 7

Fig. 6. Chaparral moved 2.61 meters from *A* to *D* between 1856 and 1906 by strain creep, and 2.06 meters from *D* to *C* in 1906 by rebound.

Fig. 7. Farallon moved 2.06 meters from *A* to *D* between 1860 and 1906 by strain creep, and 1.29 meters from *D* to *C* in 1906 by rebound.

Farallon.—Farallon Lighthouse is another important geodetic station which was located by the surveys I, II, and III. It lies 37 kilometers to the southwest of the San Andreas fault in a direction normal to its strike, and is the only station on the west side of the fault for which we have measurements of displacements for all three surveys. Fortunately these measurements are of a high order of certainty. The displacements, whether those of slow strain creep or of rebound, are remarkable for their large westerly component. The positions of the station in the years 1860, 1891, and 1906*p* are indicated by *A, B,* and *C* respectively in figure 7. The point moved 1.39 meters in the direction 153° between the years 1860 and 1891. The direction of the strain creep here is 20° more westerly than it is in the vicinity of the San Andreas fault; but at a distance of 37 kilometers the

10 *Op. cit.*, p. 126.

divergence is not great in view of our fundamental hypothesis that the strain is generated by a subcrustal flow. This flow could scarcely be parallel in all its parts, and divergences in the underflow might result in corresponding divergences in the strain creep in the overlying crust. The displacement gives us a rate of strain creep of .045 meters per year. Applying this rate to the interval 1891–1906*a* we find that the point must have moved .675 meters farther, to the position *D*. The rebound, therefore, was from *D* to *C*, a distance of 1.29 meters in the direction 101°. This displacement may be resolved into two components; one of .94 meters in the direction 144°, or parallel to the general strike of the San Andreas fault; and the other of .88 meters in the direction normal to the fault and away from it. This last figure appears to represent the same apparent transverse shift of the ground for which we found the measure to be .58 meters at Tamalpais, and .57 meters at Chaparral. The consistency of the results for all the five important stations thus far referred to is a strong argument for the correctness of the interpretation that has been put upon the data and of the underlying hypotheses upon which the interpretation is based.

Tabulation of results.—The data and their interpretation for these five stations may be conveniently summarized in tabular form as follows:

		Stations	SONOMA	ROSS MT.	TAMALPAIS	CHAPARRAL	FARALLON
		Distance from San Andreas fault	34 km. N.E.	7 km. N.E.	6.4 km. N.E.	1.8 km. N.E.	37 km. S.W.
Strain creep		Amount	1.24+ m.	1.70 m.	1.64 m.	1.83 m.	1.39 m.
Strain creep		Interval on which rate is based	1856–1906*p*	1859–1891	1854–1882	1856–1891	1860–1891
Strain creep		Direction	183°	182°	168°	173°	153°
Strain creep		Rate per year	.025+ m.	.053 m.	.058 m.	.052 m.	.045 m.
Strain creep		Total to 1906*a*	1.24+ m.	2.50 m.	3.04 m.	2.61 m.	2.06 m.
Sudden movement of 1906	Due to slip on fault	Amount		1.15 m.	1.89 m.	2.08 m.	.94 m.
Sudden movement of 1906	Due to slip on fault	Direction		324°	324°	321°	144°
Sudden movement of 1906	Apparent transverse shift	Amount		.35 m.	.58 m.	.57 m.	.88 m.
Sudden movement of 1906	Apparent transverse shift	Direction of component measured		54°	54°	51°	54°
Sudden movement of 1906	Resultant movement	Amount	0?	1.20 m.	1.97 m.	2.06 m.	1.29 m.
Sudden movement of 1906	Resultant movement	Direction		340°	341°	337°	281°

Tomales Bay Group.—The geodetic investigation proved, as Hayford and Baldwin pointed out, that a large section of the Coast Ranges, embracing at least the region between Tamalpais, Chaparral, and Farallon, moved northerly about 1.5 meters in the interval between surveys I and II. This movement was assumed by these writers to have been sudden, and to have occurred in 1868. "It is certain therefore that in 1868 the large part of the earth's surface included between these three stations, at least 700 square miles, moved about 1.5 meters in about azimuth 168°."[11] Within this territory there are ten stations near Tomales Bay which were properly assumed to have participated in this general movement. Inasmuch as the points in this group were located by surveys I and III but not by survey II, the displacement of 1906, both as to amount and direction, was found by a process of interpolation, which practically amounted to deducting the 1.5 meters of northerly movement from the total displacement found for each of the ten stations of the group for the interval between surveys I and III. The difference was taken to be the measure of the sudden displacement of 1906. The hypothesis that the northerly movement is the expression of slow strain creep which continued throughout the entire interval between surveys I and III, and of which the 1.5 meters is a partial measure, modifies the results of this interpolation, since the figures thus obtained include not only the sudden displacement of 1906 but also the strain creep between surveys II and III. It is therefore desirable to reconsider the data concerning the Tomales Bay group of stations.

Of the ten stations five are on the east and five on the west side of the San Andreas fault.

The data necessary for a discussion are tabulated below:

Station	Date of Survey I	Distance from fault Km.	Displacement between surveys I and III Meters	Direction of displacement
Point Reyes Hill	1859	2.7 W	5.15	150°
Bodega Head	1856	2.2 W	5.22	173°
Tomales Bay	1856	2.1 W	5.32	150°
Tomales Point	1856	2.0 W	5.01	151°
Foster	1856	1.9 W	6.01	149°
Mershon	1856	1.1 E	.39	330°
Smith	1856	2.6 E	.64	259°
Bodega	1860	2.0 E	.90	239°
Hans	1856	.5 E	.65	52°
Hammond	1856	1.2 E	1.75	81°

[11] Earthquake Report, vol. I, p. 124.

Of the five stations on the west side of the fault four are very consistent as to direction of displacement, while one, Bodega Head, departs notably from the mean of these. The four consistent stations are therefore taken as the best expression of the displacement on the west side. Point Reyes Hill is reduced to the same interval of strain creep as the other three stations, by adding the creep for the three years from 1856 to 1859, at the rate of .055 meters per year in the direction 173°, making the displacement for that station 5.30 meters instead of 5.15 meters.

The mean distance of the four stations, Point Reyes Hill, Tomales Bay, Tomales Point, and Foster, from the fault is 2.17 km., their mean displacement is 5.41 meters, and the mean direction of the displacement is 150°.

On the east side of the fault the results in regard to two of the stations, Hans and Hammond, are doubtful and anomalous. The other three, Mershon, Smith, and Bodega, yielded figures which are certain and consistent. These latter are taken, therefore, as the best expression of the movement of the ground on the east side of the fault. Their mean distance from the fault is 1.9 km.; their mean displacement is .64 meters; and the mean direction of their displacement is 279°. With these mean values we may construct a diagram, figure 8, which will make clear the movements of the ground on both sides of the fault. Let A be the position in 1856 of a small circle bisected by the trace of the San Andreas fault, aa'. From A, the circle migrated northerly due to the accumulation of strain for the whole period from 1856 to 1906, or fifty years. The rate of this strain creep was found to be .058 meters per year at Tamalpais and .052 meters at Chaparral. The mean of the two rates is .055 meters per year. The direction of the creep is 168° at Tamalpais, 173° at Chaparral, and 182° at Ross Mountain. The mean of the azimuths at Chaparral and Ross Mountain, which are near each other is 177°, and the mean of this and the azimuth at Tamalpais is 172°. Since the Tomales group of stations is about midway between Tamalpais and Chaparral I shall adopt 172° as the direction and .055 meters as the rate of strain creep for the group. Using this rate and direction the small circle would have arrived at B in 1906a, and the fault trace would have moved with it to the position bb'. By the slip on the fault in 1906 the small circle was severed. The semicircle on the west side moved northwesterly, and the one on the east side moved southeasterly. Both semicircles were

on the line *bb′*. But the geodetic surveys show that after the earthquake in 1906 the western semicircle was at *c* and the eastern semicircle at *c′*. Therefore the fault trace apparently shifted from the position *bb′* to the parallel position *cc′*. The actual direction of this shift, if real, is not known, but if we express it in terms of the component normal to the fault trace it measures .78 meters, as compared with .88 meters at Farallon, .57 meters at Chaparral, and .58 meters

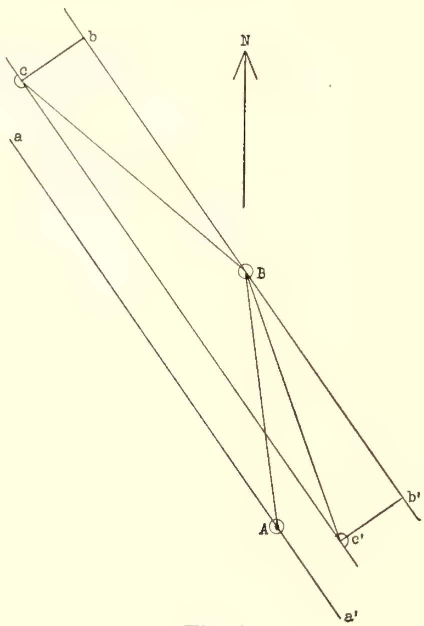


Fig. 8

Fig. 8. Tomales Bay group. A small circle located at *A* in 1856 on the San Andreas fault had moved 2.75 meters to *B* by strain creep up to 1906. By slip and rebound in that year one half of the circle moved 3.03 meters to *C* and the other half 3.00 meters to *D*.

at Tamalpais. The actual net displacement of points on the west side of the fault by sudden movement in 1906 was therefore from *B* to *c* or 3.03 meters in the direction 130°. Similarly the net displacement of points on the east side was from *B* to *c′* or 3.00 meters in the direction 340°. The distance *cc′* is the measure of the total relative displacement by the fault slip for points about 2 km. distant from the fault on either side. This is true no matter what may have been the azimuth of the transverse shift which moved the fault trace from *bb′* to *cc′*. The relative displacement by fault slip alone thus geodetically determined is 5.83 meters. The measure of the slip at the fault would

be somewhat larger. The actual maximum relative displacement at the fault trace was 6.4 meters, on the Inverness road at the head of Tomales Bay.

In the foregoing discussion it has been stated that the direction of transverse shift which brought the fault from the position bb' to cc' in figure 8 is indeterminate, and that, therefore, the distribution of the total relative slip on the two sides of the fault is also indeterminate. There are, however, some considerations which bear upon this question. It seems probable from the remoteness of the fault from the locus of no strain that the elastic fling at the time of the slip was approximately the same on the two sides of the fault. If this be admitted tentatively for the purpose of enquiring into its consequences then since the total slip is known from the geodetic measurements, we have an independent means of ascertaining the position on the fault of the small circle B in figure 8 the moment before the slip occurred. It must have been midway between the two semicircles c and c'. If we consider the slip on the fault and the transverse shift separately and suppose the latter to have followed the former, then since bb' is the total relative slip, by the assumed principle of equal fling Bb should equal Bb'. As a matter of fact they are equal by construction based on the data. But if this be so then the only possible direction of transverse shift is normal to the fault trace. I do not, however, lay stress upon this assumed principle of equal fling since I know of no means of establishing its verity. Another consequence of the equality of fling, if it could be relied upon, is that the rate of creep in the azimuth of the fault may be found. Thus if O be a small circle on the fault located, let us say, by survey I, and A the position of the semicircle on the west side and B that of the one on the east side after the slip, then AB is the total slip and $\frac{AB}{2}$ is the elastic fling. The total creep in the azimuth of the fault is $\frac{AB}{2} - OB$; and this divided by the time gives us the rate.

If, on the other hand, the apparent transverse shift be not real, but is to be explained as due to an erroneous assumption of the immobility of the Mocho–Diablo base, much of the foregoing discussion deals with an imaginary complication. It is perhaps worth noting in connection with this uncertainty that, on the assumption that the apparent shift is real and that the elastic fling is equal on the two sides of the fault, then the creep derived from the formula $\frac{AB}{2} - OB$

agrees with the creep inferred from the displacement between surveys I and II for the controlling stations, Tamalpais, Chaparral, and Ross Mountain; whereas if the apparent shift is due to a migration of the primary base the values for the creep thus independently arrived at do not agree.

Fort Ross Group.—The Fort Ross group of geodetic stations may also be reviewed to advantage in the light of the elastic rebound theory. There are twelve stations in this group, five on the east side and seven on the west of the San Andreas fault. The data necessary for their discussion are tabulated below:

Station	Date of Survey II	Distance from fault Km.	Displacement between surveys II and III Meters	Direction of displacement
Funcke	1891	0.4 W	2.33	139°
Pinnacle Rock	1891	1.6 W	2.47	158°
Fort Ross	1891	1.9 W	2.50	147°
Timber Cove	1891	1.9 W	2.22	144°
Stockhoff	1891	2.6 W	1.78	144°
Horseshoe	1891	2.9 W	1.48	137°
Salt Point	1891	3.2 W	2.01	138°
Henry Hill	1891	1.5 E	1.46	320°
Dixon	1891	1.8 E	1.37	316°
Chaparral	1891	1.8 E	1.34	328°
Peaked Hill	1891	2.0 E	1.27	301°
Lancaster	1891	2.0 E	1.77	327°

Azimuth of the fault 141°.

In addition to the determinations above listed Chaparral was also located in 1856. In 1891 it was found to have moved 1.83 meters in the direction 173°, that is in a period of thirty-five years, or at the rate of .052 meters per year. This movement was doubtless shared by all the stations in this group. Of the seven stations to the west of the fault Pinnacle Rock is anomalous in the direction of its displacement between surveys II and III; but the other six are fairly consistent both as to direction and amount. The average of these six stations, 2.05 meters in the direction 141°, is therefore taken as a better expression of the absolute displacement than the average of all seven. Of the five stations on the east side Peaked Hill is anomalous in direction, while the other four are consistent. The average of these four stations, 1.48 meters in the direction 323°, is therefore taken as a better expression of the displacement than the average of all five. With these mean values we may construct a diagram illustrating the movements of the ground. In figure 9 let *A* be the position in 1891 of a small circle bisected by the San Andreas fault, *aa′*, and *B* the point to which it

had moved by strain creep up to 1906*a*. The fault had also moved from *aa′* to *bb′*. At the time of the earthquake the small circle at *B* was severed and the two semicircles were displaced, one to the northwest and one to the northeast. They remained, however, on the line *bb′*. But the geodetic survey showed that the semicircle on the west side was at *c* and that on the east side at *c′*. The fault itself, therefore, just as in the case of the Tomales Bay group, apparently shifted from

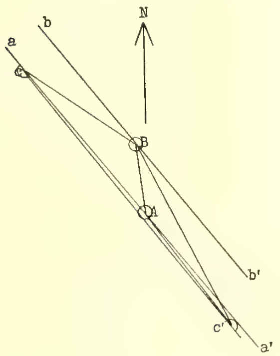


Fig. 9

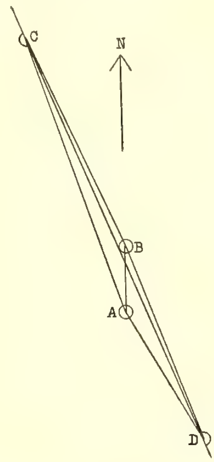


Fig. 10

Fig. 9. Fort Ross group. A small circle located at *A* in 1891 on the San Andreas fault had moved .78 meters to *B* by strain creep up to 1906. By slip and rebound in that year one half the circle moved 1.43 meters to *C* and the other half 2.2 meters to *D*.

Fig. 10. Point Arena group. A small circle located at *A* in 1891 on the San Andreas fault had moved .7 meters to *B* by strain creep up to 1906. By slip and rebound in that year one half the circle moved 2.43 meters to *C* and the other half 2.23 meters to *D*.

the position *bb′* to the position *cc′*; and *cc′* is found to be practically parallel to *aa′* and *bb′*. On the assumption that this shift is real, the actual sudden change of position at the time of the earthquake for points on the west side of the fault was from *B* to *c*, or 1.43 meters in the direction 124°; while the real movement on the east side was from *B* to *c′*, or 2.2 meters in the direction 333°. The total relative displacement by slip on the fault, thus determined as the mean of six stations on the west side and four on the east side is 3.5 meters. If, instead of taking the mean absolute displacement of the points on each side of the fault, I had used a curve such as is suggested by Hayford and Baldwin[12] to determine the mean absolute displacement at the

[12] Earthquake Report, p. 133. U. S. C. and G. S. Rpt. 1910, App. 5, p. 184.

fault, the total relative displacement would have been larger, since the amount of rebound by slip is a function of proximity to the fault. The relative displacement measured at the fault by this method is 5 meters, which checks well with 15 feet measured on offset fences, etc. The component of the apparent shift normal to the San Andreas fault is .44 meters, as compared with .57 meters for Chaparral when this station is considered alone. The distribution of the relative displacement on the two sides of the fault is, as before, indeterminate under the assumption of real shift, unless we invoke the hypothesis of equal elastic fling. If the elastic fling were the same on the two sides of the fault at the time of the slip of 1906, then the direction of the shift is 10° and its amount is .57 meters.

Point Arena Group.—The Point Arena group of stations comprises four on the east side of the fault and six on the west. The data necessary for their discussion may be tabulated as follows:

Station	Kilometers from fault trace	Displacement 1891–1906 in meters	Direction of displacement 1891–1906
Lane	.2 E	1.51	340°
Spur	.5 E	1.52	324°
Clark	3.8 E	.83	329°
Dunn	3.9 E	.79	329°
Arena	7.6 W	2.54	161°
Sinclair	6.7 W	2.57	161°
High Bluff	6.8 W	2.78	159°
Point Arena Lighthouse	6.4 W	2.45	161°
Arena Catholic Church	5.7 W	2.67	163°
Shoemake	1.5 W	3.27	164°

The directions of displacement on the west side are very consistent and average 161°. On the east side they are fairly consistent and average 330°. In considering this group I assumed that the rate of creep was the same as at Chaparral, and that the direction of creep was north. The direction of creep is somewhat more north for Chaparral than for Tamalpais; and if the direction changes the same amount between Chaparral and Arena it would be about north at the latter locality. I then plotted the record of each station in the manner that I have illustrated in the cases of Tamalpais and Chaparral. In this way I found the amount of displacement for each station from the position which it occupied, not in 1891, but in 1906*a*. The values for such displacements were then plotted in proper proportionate distances from the fault line and a smooth curve, practically a straight line, was drawn through the points as the locus of their positions.

This was done for each side of the fault separately. As a result I found that a point close to the fault on the east side should have suffered an absolute displacement of 2.23 meters to the southeast, while a similar point on the west side should have suffered an absolute displacement of 2.43 meters to the northwest. A curve constructed in this way is superior to that suggested by Hayford and Baldwin for the purpose of estimating the relation of the amount of displacement to distance from the fault. With these values we may construct a diagram, figure 10, to illustrate the movements of the ground. Let *A* be the position of a small circle bisected by the fault in 1891, *B* the position of the same circle in 1906*a* by strain creep. After the slip of 1906 the western semicircle was found by the Geodetic Survey at *C*, which is 2.43 meters from *B* in the direction 156°; and the eastern semicircle was found at *D*, which is 2.23 meters from *B* in the direction 339°. There may be some doubt in this case as to the azimuth of the fault, since in this vicinity it leaves the coast and is supposed to curve easterly through about twenty degrees so as to connect with the similar feature at Shelter Cove in Humboldt County. But whatever the orientation may be the fault moved from *A* to *B* in the interval between 1891 and 1906. The absolute displacements of the two semicircles are very nearly equal in amount and opposite in direction; and it seems probable that the average azimuth of the fault in this vicinity is expressed by the line *CD*, the bearing of which is 157°. If this be so, the apparent transverse shift is so slight that it is probably non-existent. If the shift elsewhere is to be explained by the migration of the Mocho–Diablo base then this influence is unfelt at Arena, and it is worthy of note that the triangulation in the vicinity of Arena is not shown by Hayford and Baldwin[13] to be directly connected with that base, though it is doubtless indirectly tied to it. The positions of the stations in the Point Arena group are dependent upon the Fisher–Cold Spring base, which is also assumed to have been unaffected by the crustal movements. But with the northerly strain creep at Arena as a necessary precursor of the faulting and elastic rebound in 1906, and the evidence of northerly creep of the station at Ukiah, it is difficult to concede the assumption of immobility of the Fisher–Cold Spring base. It may, however, have been advancing in the interval 1891–1906 and have sprung back in the latter year as far as it had advanced, so that the effect in locating points near Arena would have been the same as if it had not moved.

[13] Earthquake Report, Atlas, map 24.

It is interesting to note that in the vicinity of Arena the elastic fling of the ground on the two sides of the fault was practically the same in amount, and that the total differential displacement, 4.66 meters, as determined geodetically, checks closely with the displacement of 15.5 feet at the fault measured on the ground by offset fences, etc.[14]

In the foregoing discussion of the facts brought out by the geodetic survey of the region north of the Golden Gate I have applied the theory of elastic rebound as rigorously as the facts will permit. The theory calls for a strained condition of the earth's crust as a necessary preliminary to faulting. To account for this strain we must abandon the notion that the displacement, found to have occurred between surveys I and II, was a sudden movement which took place at the time of the earthquake in 1868. This notion was tentatively adopted by Hayford and Baldwin and affects many of the conclusions which they drew from the discussion of the geodetic data. The displacement which occurred between surveys I and II is here assumed to be the expression of a northerly strain creep, due to the drag of the crust riding on a subcrustal flow. The amounts of displacement for several controlling stations and the dates of the surveys of these being known, we have the rate of creep due to accumulating strain, and this may be used to find the total slow displacement up to April 18, 1906. The position before the earthquake is thus known of points which, after the earthquake, were located geodetically, and the net displacement at the time of the shock is thereby ascertained. But it is known positively and independently of the geodetic survey that a portion of this net displacement was due to slip on the San Andreas fault and was therefore parallel to it. Another element of the net displacement was apparently due to a transverse shift which carried the fault plane with it, unless the Mocho–Diablo base had moved a corresponding amount.

REGION SOUTH OF THE GOLDEN GATE

The region south of the Golden Gate appears to have suffered a more complicated series of displacements than that to the north. Here we are confronted with evidence of greater variation of movement both as to amount and direction, with a dominance of the southerly component in the net result. Here, also, we have to reckon with the displacements which caused the earthquake of 1868 and possibly that of

14 Earthquake Report, vol. 1, p. 60.

1865. The dominance of the southerly component suggests the distension of the region for which Rothpletz and Wood have proposed independent and different explanations.

In considering the geodetic data available for this region I shall continue to apply the elastic rebound theory and shall adopt the hypothesis that the results observed here are due to the operation of the same fundamental causes as in the region to the north of the Golden Gate. That is to say, I shall endeavor to show that the ascertained facts of displacement may be the consequence of the same northerly strain creep, due to subcrustal flow, as that which affected the region farther north, and that distension, in the sense of Rothpletz and Wood, may therefore be only apparent and not real.

The movement of 1868.—Before taking up this discussion, however, I will state what appears to me to be the nature of the movement which caused the earthquake of 1868, since this conception will enter into the discussion as an essential hypothesis. The evidence as to what actually happened in 1868 in the way of earth movement is scant and unsatisfactory. It is certain that the Haywards fault opened as a gaping fissure at intervals for at least twenty miles southeastward from San Leandro. At some places it stayed open and had to be bridged.[15] At other places it was sounded with a string and plummet but the bottom could not be reached.[16] This open crack was not a feature of the alluvium at the base of the hills but was found in the rock of the hill slopes. There was no fault slip on the fissure, and the displacement of a few inches which affected fences, and which occurred slowly after the earthquake, is clearly referable to later adjustments, necessitated by the lack of support for the walls of the fissure. The Haywards fault thus behaved very differently in 1868 from the San Andreas fault in 1906. The open fissure is significant not of differential displacement as a relief from shear strain, but of relief from tension. It seems to prove conclusively that there was no northerly displacement of the valley of San Francisco Bay at the time of the shock, for in this event the crack would not have opened.

It appears, moreover, that the earth wave which was generated by the displacement of the earth's crust moved from north to south. Captain Peterson while in the vicinity of Robert's Landing heard a great rumble off across the fields towards San Leandro (i.e., to the north). He looked quickly in that direction, and over a mile away

[15] *Op. cit.*, p. 444.
[16] *Op. cit.*, p. 441.

could see the great wave rapidly approaching. He rushed to the side of the road and had caught hold of the fence by the time the shock broke.[17] Mr. J. A. Graves was in the field a mile or so south of Colma with his father. Looking north they saw first San Bruno Mountain bobbing up and down; then they saw the effect of the shock on a freight train between them and the mountain, and finally they felt the shock themselves and were thrown by it to the ground.[18]

These two bits of testimony, recording observation on both sides of San Francisco Bay, seem to me to prove that the earth wave was generated to the north of these observers and moved southward.

In view of all the evidence, including personal testimony, open cracks and geodetic measurements, the most satisfactory hypothesis that can be formulated with regard to the direction of the sudden displacement of the ground in 1868 is that it was southerly. It was doubtless a rebound from elastic strain, and the relief from strain was doubtless effected by slip on a fault. There is no evidence of the outcrop of this fault, and as the region is geologically well known it is fairly certain that it does not emerge at the surface, unless possibly south of Monterey Bay. I am constrained, therefore, to believe that the slip which caused the sudden southerly movement in 1868 took place on a lowly inclined fault deep in the earth's crust.

We thus have as our working hypothesis for the event of 1868: a slow subcrustal flow in a northerly direction, generating a strain in the overriding crust, relief from this strain by rupture and slip on a flat fault, and the southerly rebound of the block above the fault, causing the earthquake. Thus explained the sudden movement of 1868 appears to differ from that of 1906 in the fact that it was an expression of the relief of the longitudinal strain, while the later movement was due to sudden relief from transverse strain.

Summary statement of displacements.—In the region south of the Golden Gate, the displacements which were measured geodetically between 1854 and 1906 are, by this hypothesis, the resultant of the following separate and distinct movements:

(1) A northerly strain creep persistent throughout the entire period covered by the surveys.

(2) A southerly elastic rebound from the longitudinal strain which had developed up to 1868.

(3) A southerly elastic rebound from the transverse strain by reason of slip on the San Andreas fault in 1906.

[17] *Op. cit.*, p. 443.

[18] *Op. cit.*, p. 445.

(4) An expansive rebound which carried the San Andreas fault parallel to itself to the southwest, if we accept the assumption of the immobility of the Mocho–Diablo base.

Rocky Mound.—The geodetic station Rocky Mound, situated 32 km. from the fault to the eastward, is on the border between the region to the south which participated in the sudden shift of 1868 and the region to the north, which did not. The border is naturally vague and indeterminate so that it is uncertain whether the station was displaced in 1868 or not. I shall therefore discuss both possibilities. The position of the station was determined in 1854, 1885, and in 1906*p*. Assuming first that the station was not displaced in 1868 the displacement of .5 meters in the direction 188° between 1854 and 1885 gives us a rate of strain creep of .016 meters per year. In figure 11, I, let

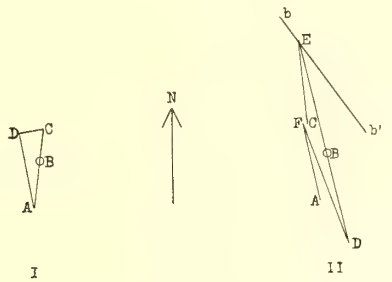


Fig. 11, I. The path of Rocky Mound under the assumption of no displacement in 1868.
Fig. 11, II. The path of the same station if displaced in 1868.

A represent the position of the station in 1854 and *B* its position in 1885. At the rate deduced the point would have been at *C* in 1906*a*. But after the earthquake it was found at *D* by the Geodetic Survey. If the station moved in 1906 by reason of the slip on the San Andreas fault, the direction of movement due to that cause must have been parallel to the fault, or in the direction 306°. There is thus an apparent transverse shift of about .25 meters, which may be real or may be explained as before by the migration of the Mocho–Diablo base.

Secondly, we may assume that Rocky Mound was suddenly displaced to the south in 1868. In this case let *A* in figure 11, II, represent its position in 1854, *B* in 1885, and *C* in 1906*p*. Under this assumption there is no basis in the data for deducing the rate and direction of creep, and I shall therefore adopt the rate found at Tamalpais of .058 meters per year in the direction 168° for the purpose of illustrating the general path of the station under the hypothesis

of continuous stress and successive reliefs from the consequent strain. In the interval between 1854 and 1868 the station should have moved $.058 \times 14 = .812$ meters in the direction 168° to the point *F*. In arriving at *B* in 1885 the station was creeping northerly and had been doing so since 1868*p*. It had thus moved in the direction 168° for seventeen years at the rate of .058 meters per year. This gives us the position of the station at *D* in 1868*p*. The line *FD* is therefore the measure and direction of the rebound of 1868 for this station. This creep continued in the same direction from 1885 to 1906*a* and brought the station to *E*. From *E* it rebounded to *C* in 1906. But the movement due to slip on the fault in 1906 was in the direction 306°, along the line *bb'*, and could only have arrived at *C* by a transverse shift, unless C be located too far south by reason of the assumption of immobility for the Mocho–Diablo base. This second assumption, that Rocky Mound participated in the sudden displacement of 1868, yields results which are consonant with the behavior of other stations in the region to the south, whereas the first assumption of stability in 1868 places it in an anomalous situation with regard to the behavior of stations north of the Golden Gate.

Red Hill.—Red Hill is 19 km. distant from the fault to the eastward. Its position was determined in 1854, 1885, and 1906*p*. The displacements found by these surveys were: .65 meters in the direction 232°, between 1854 and 1885, and .30 meters in the direction 215° between 1885 and 1906*p*. These figures suggest that the *direction* of movement was away from the fault and nearly normal to its strike. This suggestion may, however, be fallacious and the station may have followed a devious path. To illustrate, let *A, B,* and *C,* figure 12, be the positions at which the station was found in 1854, 1885, and 1906*p* respectively. We may first follow the path of the station for the period after 1885. At this date the station was at *B,* moving northerly by strain creep. I shall assume the rate of this creep to be the same as that found at Tamalpais, or .058 meters per year. In the interval of twenty-one years between 1885 and 1906*a* the station must have travelled 1.22 meters and have been somewhere on the circle *aa'*, which is drawn from the center *B* with the radius 1.22 meters. If now the sudden movement in 1906 were wholly parallel to the fault, then the line *cC,* drawn through *C* in the direction 144°, would be the path of the station for that movement, and the point of intersection of *cC* with the circle *aa'* would be the position of the station in 1906*a*. But the sudden movement of 1906 involved, besides the slip parallel to the

fault, an apparent transverse shift whereby the fault was moved parallel to itself to the southwest. I shall, therefore, allow for this and assume that the station in 1906*a* was on the circle *aa′* at *D*, a little to the east of the point of intersection of the line *cC*. Then the line *DB* is the azimuth of strain creep, and this is 163°. The exact position of *D* is uncertain, but its departure from *c* is doubtless a small quantity, and the position assigned to it will serve my present purpose, which is not to arrive at exact numerical expressions for the various displacements, but to develop a consistent hypothesis as to the

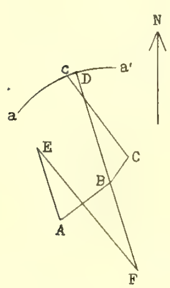


Fig. 12

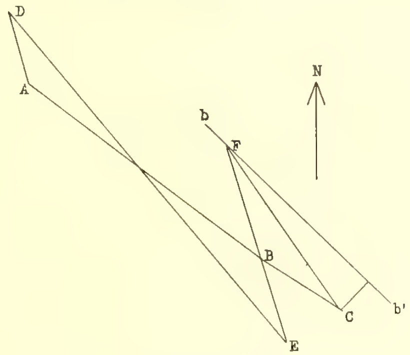


Fig. 13

Fig. 12. The path of Red Hill as determined by strain creep and the rebounds of 1868 and 1906.

Fig. 13. The path of Loma Prieta as determined by strain creep and the rebounds of 1868 and 1906.

general path of a station between 1854 and 1906*p* in the disturbed region south of the Golden Gate. But if *BD* be the direction of strain creep then the path of the station from 1854 to 1868*a* must have been on the same azimuth. It is fair to assume, therefore, that in this interval of fourteen years the station moved $.085 \times 14 = .812$ meters in the direction of 163°. Thus we have the position of the station just prior to the sudden movement of 1868, at *E*. Similarly after the earthquake of 1868, the station moved from *F* to *B*, .98 meters in the direction 163°, so that the position of the station immediately after the sudden movement of 1868 is also known. The line *EF* gives us, therefore, both the amount and the direction of that sudden movement, which was 1.68 meters in the direction 321°. Thus, by way of summary, the path of the geodetic station Red Hill between 1854 and 1906*p* was from *A* to *E* by slow strain creep, from *E* to *F* by sudden rebound in 1868, from *F* to *D* by renewal of strain creep, and from *D* to *C* by sudden rebound in 1906. The last movement from *D* to *C*

was chiefly parallel to the San Andreas fault, but on the assumption of transverse shift there was also a small component of movement normal to the fault.

Loma Prieta.—Let us next consider Loma Prieta, for which we have surveys in 1854, 1884, and 1906*p*. The geodetic data are: between 1854 and 1884 the station had been displaced 3.03 meters in the direction 307° and between 1884 and 1906 an additional .97 meters in the direction 303°. I shall assume that the persistent northerly strain creep was in the same direction as that adopted for Red Hill, or 163°, although it may have been a few degrees more to the west; and the rate of this strain creep I shall again take at .058 meters per year.

In figure 13, let *A* be the position of the station in 1854, *B* its position in 1884, and *C* in 1906*p*. By 1868*a* it would have moved to *D*, or .812 meters in the direction 163°. In arriving at *B* in 1884 the station must have moved by strain creep in the direction 163° from the point to which it was suddenly shifted in 1868. In 1868*p*, therefore, Loma Prieta was at *E*, $.058 \times 16 = .928$ meters from *B*. The line *DE* is the measure of the sudden movement of 1868. This is 4.57 meters in the direction 320°. After 1884 the station continued its northerly migration until 1906*a*, when it had arrived at *F*, 1.27 meters from *B* in the direction 163°. From *F* it rebounded, at the time of the earthquake, parallel to the San Andreas fault, which here has the strike of 135°, and was therefore on the line *bb′*. But after the earthquake it was found at *C*; so that the line *bb′* was apparently suddenly shifted parallel to itself to *C*. This shift, measured normal to the fault, amounts to .40 meters, and is the same apparent transverse shift that was recognized in the stations north of the Golden Gate. These last two movements, one parallel to the fault, the azimuth of which is known but the amount not, and the other, of which only the component normal to the fault is known, together make up the net sudden displacement of the station on April 18, 1906, from *F* to *C*, or 2.10 meters in the direction 325°. Thus between 1854 to 1906*p*, Loma Prieta moved first by strain creep from *A* to *D*, then by rebound from *D* to *E*, then by renewed strain creep from *E* to *F*, and again by rebound from *F* to *C*.

Gradient of displacement.—It is noteworthy that while the sudden movement of Red Hill in 1868 was 1.68 meters to the southeast, that of Loma Prieta was 4.57 meters, or 2.72 times as much. This fact consists with the hypothesis that the sudden movement which caused the earthquake of 1868 was confined to the region south of the Golden

Gate. If this be so, then there must be a locus in the vicinity of the Golden Gate, transverse to the direction of that movement, on which the movement was zero. If as I have already suggested, the earthquake of 1868 was caused by rebound on a flat fault, then the measure of that rebound, being the relief from elastic compression, would be progressively and regularly greater from north to south. If this be so then we may locate approximately the zero point of the slip on the flat fault. For we can take the measures of the rebound at Loma Prieta and Red Hill and therefrom construct a gradient, the rebound being proportional to the southerly departure of the stations from the zero point of slip. Thus in figure 14 let *AB* represent the distance

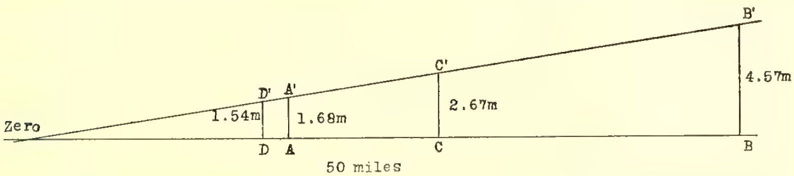


Fig. 14. Gradient of displacement by elastic rebound in 1868 between San Bruno Mountain and Loma Prieta.

between Red Hill and Loma Prieta, and make *AA′ and BB′* proportional to the sudden shifts of these stations in 1868. Then the line *A′B′* affords the measure of the same shift for any other station to the north of Loma Prieta. The zero point of shift is thus found to be at San Bruno Mountain, fifty miles from Loma Prieta. The shift of 1868 at Black Mountain, *CC′*, was 2.67 meters, and at Pulgas West Base, *DD′*, was 1.54 meters. The shift at Sierra Morena was the same as that at Red Hill.

Black Mountain.—Using now this inferential information we may arrive at the movements of those stations which were located by surveys I and III but not by II. In the case of Black Mountain let *A* in figure 15 be the position of the station in 1854 and *B* the position in 1906*p*. Between 1854 and 1868 the movement would have been by strain creep .812 meters in the direction 163° to *C;* thence by rebound 2.67 meters in the direction 320° at the time of the earthquake of 1868 to *D;* thence between 1868 and 1906*a*, by renewal of the strain, 2.2 meters in the direction 163° to *E;* thence by rebound in 1906 southeasterly along *bb′* parallel to the San Andreas fault an unknown distance compounded with an apparent transverse shift which brought it to *B*. The component of the transverse shift normal to the fault is .78 meters.

Pulgas West Base.—Pulgas West Base was located in 1853 and again in 1906*p*, but not in the interval between. In figure 16 let *A* be the earlier position and *B* the later. In the interval 1853–68 the station moved .87 meters in the direction 163° by strain creep to *C;* thence by rebound in 1868 1.54 meters to *D;* thence by renewed strain creep 2.2 meters to *E* in 1906*a*; thence, by rebound, southeasterly parallel to the San Andreas fault an unknown distance, on the line *bb′*, compounded with an apparent transverse shift which brought it to *B.*

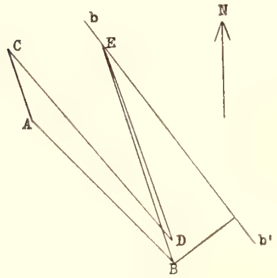


Fig. 15

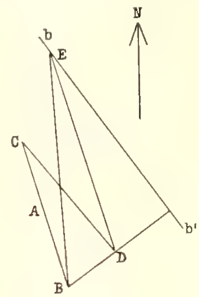


Fig. 16

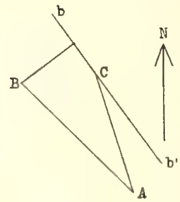


Fig. 17

Fig. 15. The path of Black Mountain as determined by strain creep and the rebounds of 1868 and 1906.

Fig. 16. The path of Pulgas West Base as determined by strain creep and the rebounds of 1868 and 1906.

Fig. 17. The path of Sierra Morena as determined by strain creep and the rebound of 1906.

The component of the transverse shift normal to the fault is in this case 1.33 meters, an exceptionally large figure, suggestive of a slight error in the azimuth *AB.*

Sierra Morena.—Sierra Morena on the west side of the fault was located in 1883 and again in 1906*a*. It is situated 4.3 km. from the fault. In figure 17 let *A* be the earlier position and *B* the later. In the interval of twenty-three years between 1883 and 1906*a* the station would have moved $.058 \times 23 = 1.33$ meters in the direction 163° to *C.* At the time of the earthquake in 1906 it moved by rebound northerly parallel to the fault on the line *bb′*. But after the earthquake it was found at *B*. The line *bb′* was apparently shifted parallel to itself to *B*, and the component of this transverse shift normal to the fault is .69 meters.

Mt. Toro.—Mt. Toro, situated on the west side of the San Andreas Rift but south of the region of slip in 1906, probably did not move at the time of the earthquake of that year. At least there is no evidence, or even suggestion, that it did. The station was located in 1885 and

again in 1906*p*. In the interval of twenty-one years it was found, on the assumption that Santa Ana had not moved, to have been displaced 95 meters in the direction 168°. This displacement, I take it, represents strain creep unaffected by subsequent rebound. The rate of strain creep is, therefore, .045 meters per year.

Gavilan.—Gavilan is also south of the region of slip on the San Andreas fault in 1906, and probably suffered no rebound in that year. Its position was located in 1854 and in 1906*p*, but not in the interval

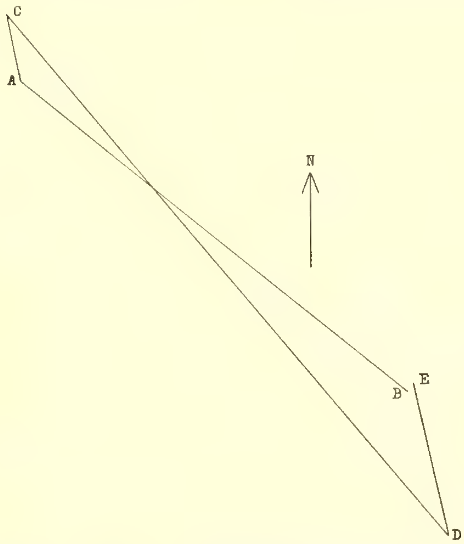


Fig. 18. The path of Gavilan as determined by strain creep and the rebound of 1868.

between. Between these dates it was found to have been displaced 5.2 meters in the direction 309°. The path of its movements may be found under the hypothesis here adopted by use of the accompanying diagram. In figure 18 let *A* be the position in 1854 and *B* that in 1906*p*. Using the rate and direction of strain creep found at Toro, namely .045 meters per year in the direction 168°, the station would have arrived at *C* in 1868*a*, .812 meters from *A* in the direction 168°. The sudden shift of 1868 is found, by the gradient above referred to, to be 7.20 meters; and this was probably in the same direction as the same movement of Loma Prieta, or 320°. This would bring the station in 1868*p* to *D*. From *D*, moving in the direction 168°, the station by strain creep would have arrived in 1906 at *E*, 1.71 meters from *D*, which checks very closely with the position at which it was actually found at *B*, only about .1 meter away. The closeness of the check is

probably a coincidence, for we are now in a region where the geodetic data are less certain than they are to the north. The amount of displacement of Gavilan is postulated on the immobility of Santa Ana. But while Hayford and Baldwin[19] appear to be justified in their assumption that Santa Ana suffered no displacement in 1906, it is probable that this station has participated in the strain creep of the region, and it is not improbable that it moved suddenly in 1868. The position of Santa Ana was determined in 1852 and its change of position between that date and 1906*p*, whether by strain creep or rebound, would seriously affect the measure obtained for the displacement of Gavilan.

Santa Cruz and Point Pinos.—Santa Cruz and Point Pinos are somewhat anomalous, particularly in the azimuth of their direction of displacement. The uncertainty as to the movements of Santa Ana, however, renders futile any attempt to discuss the behavior of the stations at these places. Under certain plausible assumptions as to the movements of Santa Ana between 1852 and 1906*p*, consistent with the hypothesis of strain creep and rebound, a large part of the supposed displacement of Point Pinos and Santa Cruz might be unreal. If, contrary to probability, Santa Ana were immobile between 1852 and 1906*p*, then the ascertained displacements of both Point Pinos and Santa Cruz may be made consistent with the displacements of other points nearer the San Andreas fault by assuming a larger azimuth for the direction of rebound in 1868.

The Colma Group.—The behavior, in 1906, of the group of geodetic stations near Colma, comprising Flat Road, False Cattle Hill, and San Pedro Rock to the west of the San Andreas fault and Black Bluff, Black Ridge, and San Bruno Mountain to the east, is anomalous. The anomaly, however, is not of the same kind on the two sides of the fault. On the east side of the fault it appears in the smallness of the amount of displacement; while on the west side, although the amount of displacement is approximately normal, the direction of that displacement has a notable component toward the fault. Both anomalies may perhaps be referred to a common cause inherent in the geological structure of this part of the region. Immediately to the east of the San Andreas fault, between it and San Bruno Mountain, is a deep wedge of late Tertiary sediments, comprising the Merced and later formations, which are relatively incoherent and inelastic.[20] Such

[19] Earthquake Report, vol. I, p. 130.

[20] See U. S. G. S. 15th Ann. Rpt., pp. 459 *et seq.;* also folio 193, pp. 14–16.

sediments are incapable of accepting a condition of elastic compression. Any stress applied to them would not generate a condition of strain, but would be dissipated in plastic deformation. It is, therefore, highly probable that although the firm rock below the Merced may have been in a condition of strain, this strain could not have been communicated to this body of sediments. They, therefore, lacked in large measure the ability to rebound when the strain of the region was relieved by the slip on the San Andreas fault. It is true that they might have been carried south by the elastic rebound of the underlying firm rocks, but, owing to the suddenness of this rebound, the principle of inertia would operate to restrain movement at the surface, and the tendency would have been largely quenched in plastic deformation. It is thus comprehensible that in the Merced terrane the condition of transverse strain prerequisite to rebound was lacking, and that, therefore, in the upper mile of the crust the transverse strain could not be transmitted to the firm rocks of San Bruno Mountain and Black Ridge, so that their tendency to rebound was also feeble.

The eastward component of motion of the ground on the west of the fault may be explained by a deformation of the fault plane itself, due to a slight east-west condensation of the wedge of Merced sediments. At the time of the slip in 1906 the large east-west component of the free elastic force on the west side of the fault may have been sufficient to stove in the fault plane towards the feebly resistant wedge of inelastic Merced strata.

APPARENT DISTENSION

Certain phenomena of apparent distension call perhaps for a special discussion. Hayford and Baldwin[21] first directed attention to the fact that in the interval between surveys I and III there was an increase of 3 meters in the distance between Tamalpais and Black Mountain, of 2 meters between Black Mountain and Loma Prieta, of 1.2 meters between Loma Prieta and Gavilan and of 3 meters between Santa Cruz and Point Pinos. The last mentioned increase is somewhat doubtful owing to the assumption of immobility of Santa Ana, the controlling station, but there seems to be no reason for doubting the reality of the others. This increase of the distances between geodetic stations was taken by both Rothpletz and Wood as significant of a deep-seated distension of the region. The phenomena are, however,

[21] *Op. cit.*, pp. 132–133.

susceptible of satisfactory explanation on the hypothesis of a persistent northerly strain creep throughout the entire region, with a southerly rebound in 1868 of that part of it south of the Golden Gate. This hypothesis involves the notion of an elastic prism released from compressive drag so as to rebound in one direction only. The measure of rebound will increase regularly in an arithmetical ratio from the fixed or zero point toward the free end. Thus if Tamalpais were unmoved in 1868, the rebound from compression of the block to the south would increase the distance between that station and Black Mountain. For points north of Black Mountain, but south of the locus of zero movement in 1868, the increase of distance from Tamalpais would be less, and for points south greater. There must be, of course, a limit to

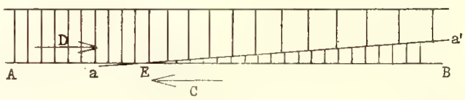


Fig. 19. Effect of relief of longitudinal strain on a lowly inclined fault.

this expansive rebound, but at present we do not know where it is, except that it is beyond Gavilan to the southward. The arithmetical ratio of increase of the measure of rebound applies only to the sudden movement of 1868 and not of course to the geodetically measured distances, since the increase of distance is due to the rebound of that year less strain creep between surveys I and III plus the rebound of 1906 for Black Mountain and Loma Prieta, but without any increment in 1906 for Gavilan.

The notion that the entire region is subject to a persistent northerly flow stress, while only the part of it south of the Golden Gate rebounded in 1868 on a presumed flat fault, implies a residual strain in the region north of the Golden Gate. That this is mechanically possible may be appreciated by reference to the diagram, figure 19. Let *AB* represent the line of demarcation between the zone of flowage and the zone of rupture. The arrows *C* and *D* represent the directions of stress and strain respectively, and *aa′* is a flat fault upon which a slip has just occurred. This fault intersects *AB* at *E*. Below *E* the fault cannot persist as such into the viscous zone. The slip, therefore, is only effective for the portion of the overriding crust to the right of *E* and above *aa′*. In this segment of the crust the rebound takes place. To the left of *E* above *AB* the stress has operated continuously

and the strain is still maintained. To the right of E between AB and aa' the stress has also operated continuously and the strain is maintained. In the portion of the crust that has been relieved of strain an expansion has occurred, the measure of which is proportional to the distance from E, the zero point of the rebound in a given section. In the region south of the Golden Gate the locus of E passes through San Bruno Mountain.

SUMMARY

I have now reviewed, in rather summary fashion, the results of the geodetic surveys and have interpreted them in the light of the elastic rebound theory of faulting. The working hypothesis of the paper is the validity of the theory, which states that faults and consequent earthquakes are due to sudden relief from compressive strain by rupture, or by movement on old rupture planes. In the seismic region of the middle Coast Ranges the causal stress of this strain is probably a northerly slow subcrustal flow which is indicated by the displacement of several geodetic stations in the interval between surveys I and II. The more important of these stations are to the north of the Golden Gate and to the east of the San Andreas fault. In each case, the amount of displacement and time interval being known, the rate of movement is ascertained. The movement itself is interpreted as the expression of strain creep due to the northerly stress. The northerly migration of the Ukiah station of the International Latitude Service, and of Lick Observatory, sustains the hypothesis of a northerly strain creep which affects the whole region. The strain generated by the northerly stress has a twofold distribution: (1) A longitudinal strain, opposed in direction to the general stress, which is relieved by lowly inclined, deep faults having a strike normal to the direction of stress; and (2) a transverse strain, due to the unequal distribution of the stress in the horizontal sense, which is relieved by vertical faults having a strike oblique to the direction of stress. The longitudinal strain for the portion of the region south of the Golden Gate was relieved at the time of the earthquake of 1868, while the transverse strain for the whole of the region considered was relieved by a slip on the San Andreas fault in 1906. The absence of any evidence of rebound in 1868 in the territory north of the Golden Gate is the warrant for assuming that none occurred. The hypothesis that the rebound of 1868 in the territory south of the Golden Gate was southerly, and that the measure of this rebound increased regularly to the

southward from a locus of zero movement near San Francisco, agrees with and explains many facts. In the absence of the outcrop of any vertical fault, functional at that date, we are forced to assume slipping on a fault of low dip which is not known to emerge at the surface. This conclusion and the application of the principle of elastic rebound, enables us to explain practically all the facts without recourse to the notion of distension, which was first suggested by Hayford and Baldwin, tentatively accepted by myself, and finally adopted by Rothpletz and Wood. The distension, as regards at least the causal flow, becomes unreal, and all the phenomena are accounted for by the operation of a persistent northerly subcrustal flow, generating in the overriding crust a state of strain, which is relieved from time to time by rebound slips on faults, both highly inclined and flat, each slip causing an earthquake. The fundamental weakness in the data upon which the discussion is based is the uncertainty as to the immobility of the geodetic base Mocho–Diablo. If it be assumed, with Hayford and Baldwin, that this base was unaffected by the strain creep, then we are forced to recognize a transverse shift of the region supplementary to the slip on the San Andreas fault in 1906. If the Mocho–Diablo line upon which the triangulation was based migrated northerly then the apparent transverse shift becomes unreal, and is easily explained by that migration. But if the Mocho–Diablo base participated in the strain creep then the quantities for the rate of strain creep and northerly rebound on the west side of the San Andreas fault would in several cases be increased, while the quantities for the southerly rebound on the east side of the fault would in most, if not all cases, be diminished. In view of this uncertainty I have sought throughout the paper merely to develop the general consequences of the validity of the elastic rebound theory, rather than to arrive at precise measures of either strain creep or rebound.

One gratifying thing about the hypothesis of persistent northerly strain creep as a local manifestation of the principle of elastic rebound is that it is susceptible of verification or disproof. As the work of the U. S. Coast and Geodetic Survey proceeds we will know with exactness the geographical position of many points in the Coast Ranges of California. In the light of the elastic rebound theory of faulting it is no longer permissible to assume that changes in position, such as were discovered after the earthquake of 1906, are due wholly to sudden shifts which occur at the times of earthquakes. The theory teaches that sudden shifts can occur only after the accumulation of

strain to a limit and that this accumulation involves a slow creep of the region affected. In the long periods between great earthquakes the energy necessary for such shocks is being stored up in the rocks as elastic compression. The relief from such compression by fault slip of course indicates a sudden shift of ground, and therefore a sudden change of geographic position, which is a matter of great concern to the Coast and Geodetic Survey. But the changes in latitude and longitude due to the preliminary strain creep are not less in magnitude and of no less concern to the Survey than the sudden shifts at times of faulting and earthquake. In order to render the surveys consistent and to make proper adjustments, it will be necessary to ascertain both the rate and direction of strain creep in this mobile portion of the earth's crust. In the course of their regular duties, therefore, officers of the Survey will acquire the data necessary not only to establish on a firm basis the fact of strain creep, but also its rate and direction, with their variations.

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ERRATA

Page 438, first item in fourth column under "Latitude." *For* 37° 20′ 26″87 *read* 37° 20′ 25″87.

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